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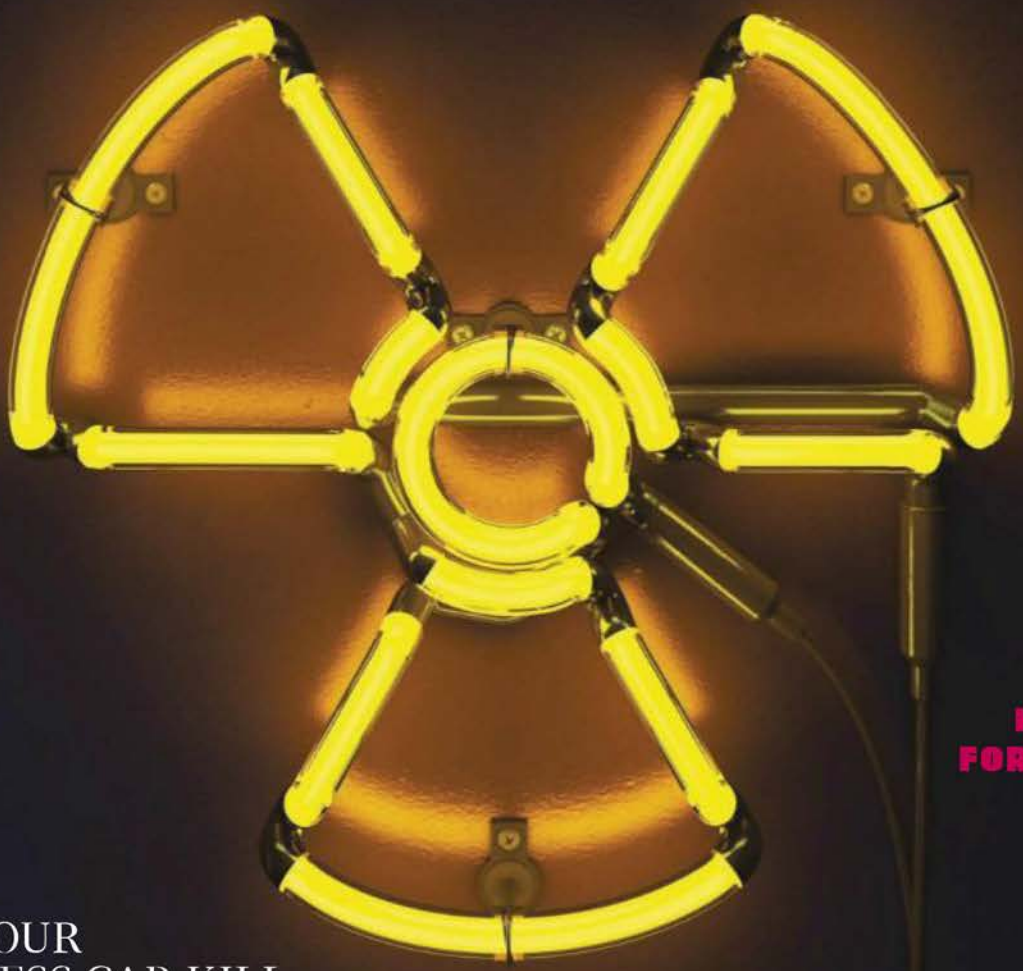
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WELCOME



Our long and troubled relationship with fossil fuels is coming to an end. Though estimates vary, it seems reasonable to say that by the end of the century there won't be many fuels left to burn. Something has to take their place.

China, India, Russia, South Korea and the US have been building more and more nuclear power plants to lend their fledgling renewable energy supplies a hand. Europe, on the other hand, has slowed down its production, while the UK hasn't built a new nuclear power station in a generation.

This year marks the 5th anniversary of the Fukushima disaster, and as the UK debates whether or not to build a new power plant at Hinkley Point, we ask: can we afford to neglect nuclear power any longer? The answer, on p36, might surprise you.

You might also be surprised to find out that scientists in a laboratory in Edinburgh are trying to recreate the birth of a planet. More precisely, they're squashing atoms in a vice made from diamond to four million times the atmospheric pressure of Earth. Find out what they've achieved on p52.

Meanwhile in London, Bristol, Milton Keynes and Coventry, engineers are testing out the abilities of driverless cars. But what happens when the artificial intelligence behind the wheel needs to make a life or death decision? What if it saves lives at the cost of your own? We weigh up the choices on p72. Enjoy the issue!

Daniel Bennett

Daniel Bennett, acting editor

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HEATHER BRADSHAW-MARTIN
Automotive software engineer Heather puts her PhD in bioethics to good use this month, investigating the moral dilemmas faced when programming driverless cars. → p72



MARK MIODOWNIK
This month, materials scientist Mark takes on top chef Marcus Wareing in BBC Four's *Chef vs Science: Ultimate Kitchen Challenge*. We catch up with Mark to find out his top chemistry-based cooking tips. → p103



NEIL ASHTON
It's been 80 years since the maiden flight of doomed German airship the *Hindenburg*. Aerospace engineer Neil takes a looks at the fleet of new airships about to take to the skies. → p58

COVER: MAGIC TORCH

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44 Thanks to drones, GPS trackers, and other high tech devices, we now know more about animals' movements than ever before.

Building a planet on Earth

52 We can't send a spaceship inside a gas giant like Jupiter to see what goes on there, so can we recreate the same conditions here on Earth? A bunch of scientists are giving it a go...

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58 Some 80 years on from the *Hindenburg* disaster, and with reducing CO_2 emissions a priority, is it time for airships to make a comeback?

Your future smart home

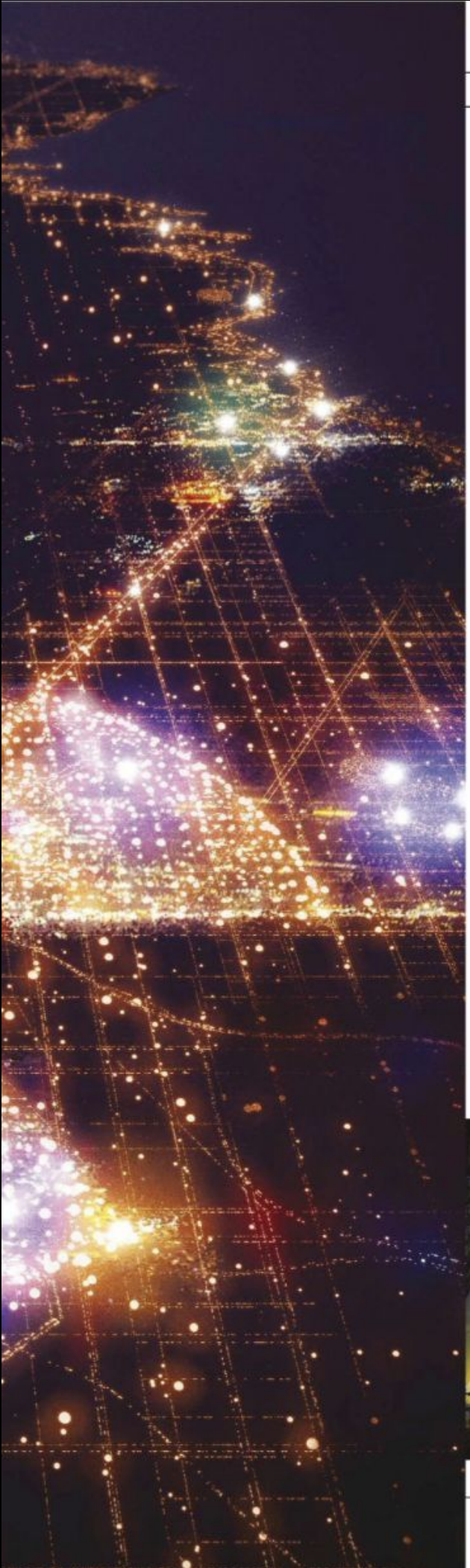
66 Nest thermometers and internet fridges are only the start: every part of your home can now get a high tech makeover (if you want it to).

Could your driverless car choose to kill you?

72 Autonomous vehicles are built with safety firmly in mind but sometimes that might not turn out to be in the driver's best interests.

How do we know... how to predict the weather?

94 A brief history of weather forecasting, and how this once hit and miss enterprise has become a far more exact science.





72


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58

You're gonna need a bigger boat

ULSAN SHIPYARD,
SOUTH KOREA

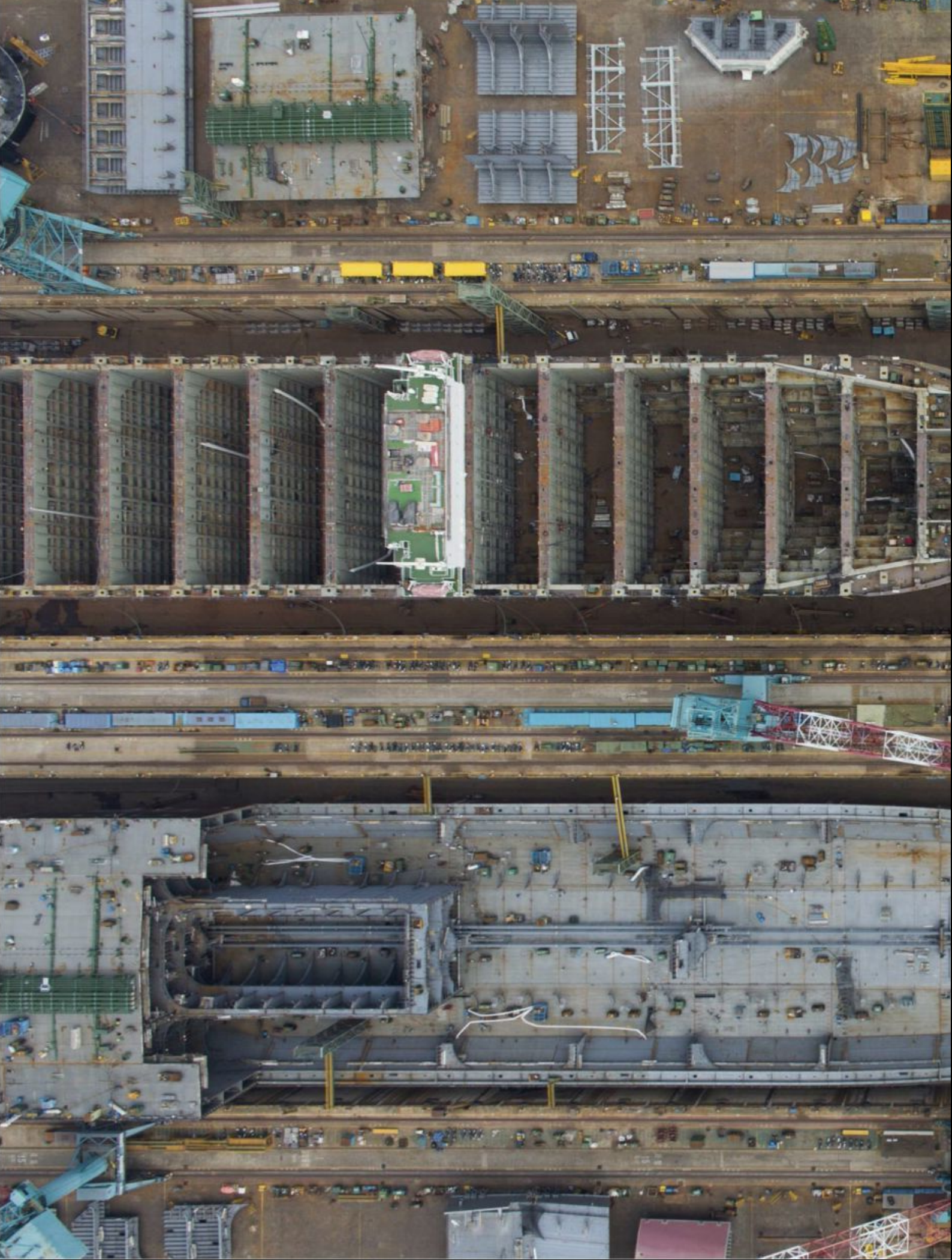
If you ever find yourself quoting Chief Brody's famous line from *Jaws*, you should head to Ulsan Shipyard in South Korea.

Owned and operated by Hyundai Heavy Industries, the 1,780-acre site in Mipo Bay is the largest ship-building facility in the world, capable of turning out 70 new ships each year. Not just any ships, mind you – the biggest oceangoing vessels on the planet, including gargantuan container ships and tankers for liquefied natural gas.

Despite being taken from high above, this shot still isn't big enough to completely frame one of Ulsan's 10 dry docks, the biggest of which measures a staggering 672 x 92 x 12m. Spanning those docks are nine aptly named Goliath gantry cranes, two of which can be seen disappearing out of the top and bottom left of this image. The cranes, which stand 117m tall and 210m wide – big enough to straddle not just a football pitch but the entire Emirates stadium – are used to lift vast sections of the boats' hulls into position so they can be welded together.

Robots do most of the welding at Ulsan simply because they can weld faster and more accurately than their human counterparts. Nevertheless, every weld has to be checked on a microscopic scale to ensure its integrity as even the slightest fault can lead to an explosive disaster when you're transporting vast quantities of gas or oil.

PHOTO: GETTY





EYE OPENER

Lava land

KAMCHATKA,
RUSSIA

Everyone knows that "one does not simply walk into Mordor". So anyone wanting to get their fill of black, craggy rocks, menacing volcanoes and smoking lava flows without invoking the wrath of Sauron should head for Kamchatka. Sitting at the far eastern edge of Russia, the Kamchatka peninsula is the most volcanically active area on the Eurasian continent, and is littered with spectacular sights – like the lava tube shown here.

After a volcanic eruption, lava tends to flow in distinct channels. As the overflow from these streams cools, the lava begins to solidify. Over time, the flowing lava melts the ground below it, making the furrow deeper while the embankments left above eventually connect, forming a canopy.

Lava tubes can be found all over the world, but are most likely to occur in areas where the lava is especially fluid.

PHOTO: DENIS BUDKOV



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MESSAGE OF THE MONTH

Solar system

In the January edition of *BBC Focus*, I was fascinated by the news article on batteries made from algae. While studying for a degree in environmental science, I came across the electrical pathways in natural systems and wondered if these could be harnessed to generate power for human purposes. Now, having read the article, I wonder if these blue-green organisms could be used to form a new kind of solar panel, which not only produces electricity but also absorbs carbon dioxide through photosynthesis? Furthermore, when these organisms die, they could be stored in tanks to produce methane (biogas) during their decomposition. If this could be done, each community could have a biological power supply and fuel for heating and cooking. The emissions from burning the gas would be absorbed by a fresh supply of algae to the panels, creating a renewable, net zero CO_2 emission system.

This may, of course, not be possible or practical, but I would like to think it is. I am sure that tanks of algae for sequestering CO_2 and producing biogas already exist, so perhaps it might not be such a huge leap to combine this with power generation?!

Paul Martin, Deeside

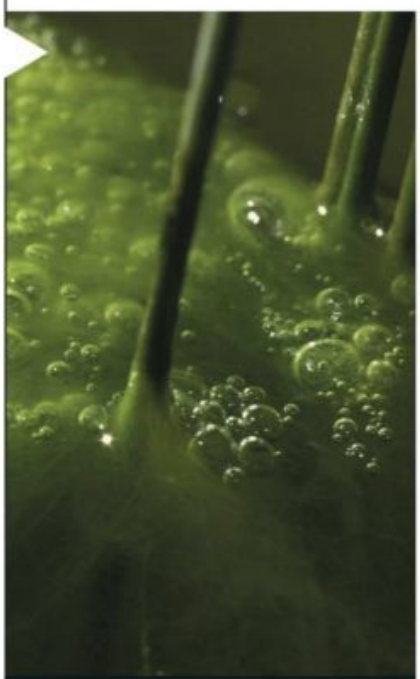
Paul, you've sharply hit upon several research projects already underway. Unfortunately, it seems that algae-infused solar cells just don't convert sunlight into electricity efficiently enough to be a viable solution to our energy needs right now. But a holistic approach like yours might go some way towards boosting the power output of these little microorganisms. In the meantime, check out p36 for our take on how we could keep the lights on here in the UK. – ***Ed***

WRITE IN AND WIN!

The writer of next issue's *Message Of The Month* wins a **LIFX Color 1000 bulb, worth £59.99**. The bulb has built-in Wi-Fi and is combined with an app so you can adjust the colours for a perfect atmosphere. For more information, visit **lifx.com**



PHOTO: GETTY



Paul Martin thinks that we could harness blue-green algae to generate zero emissions power

Old in the tooth

On p20 in the January issue, I was somewhat bemused to read about the 'discovery' of using a 'fluoride varnish' to reduce the need for fillings. In the Community Dental Service in this country we were using this technique over 25 years ago (it was called Duraphat). More than 35 years ago we were recommending regular dental check-ups and careful daily tooth cleaning. I am reminded of the words of Samuel Taylor Coleridge in 1831: "If men could learn from history, what lessons it might teach us! But passion and party blind our eyes, and the light which experience gives us is a lantern on the stern, which shines only on the waves behind us!"

John Furniss, Cheltenham

Food for thought

As I sit with an excellent Rioja, waiting for the pasta to boil, I have opened my eagerly awaited February issue of *BBC Focus* and am reading the excellent article about the hunt for alien life. Bradley Schaefer disagrees that the dimming of KIC by comets is "completely implausible". Yet, here we are, humanity and its entourage, writing articles and drinking Rioja – what could be more implausible than that? We think we know so much, but I reckon we ain't seen nothing yet. After all, who could possibly have foreseen humanity?

Diarmid MacArthur, Lochwinnoch

The blinking of KIC 8462852 remains a mystery. Who knows what they might find? Cheers! – ***Ed***

Better the devil you know?

I disagree with Bill McGuire's suggestion that naming storms makes them "sound friendlier and more cuddly" (January, p79). The Met Office adopted this idea in order to make the public more aware. In the UK, where miserable but not extreme weather is the norm, we can switch off when there's a forecast of another band of heavy rain. Naming a storm makes us think of extreme events such as hurricanes and typhoons – it gives them an identity. As weather becomes more extreme, it lets us know what's coming.

I think the naming process has had a positive effect. I've noticed friends and colleagues discussing the weather more. Those that live in areas that were hit by floods took precautions earlier because they were aware that a specific storm was on the way. They still suffered damage, but it was less extreme than it could have been.
Laura Whittaker, via email

For some reason, storm names like Steve and Nigel just don't alarm us... – ***Ed***

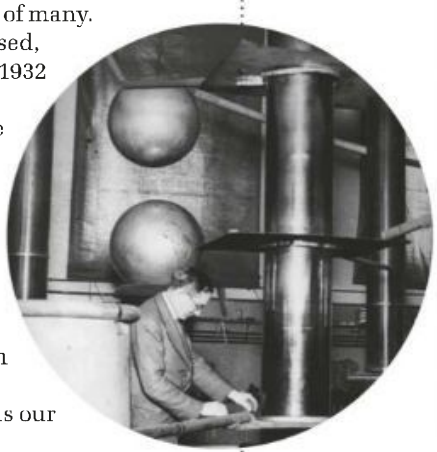


Laura Whittaker thinks that naming storms is a good idea

Back to the future

I am in full agreement with your recent article that suggests 2015 will go down in history as one of the best years for science (Christmas, p32). The past 12 months have seen some incredible advances and discoveries, with the landing on Comet 67P and the exploration of the Pluto system by New Horizons being just two highlights out of many.

I was surprised, however, that 1932 did not get a mention in the 'best of the rest' section. In this year, several significant discoveries were made in physics, which contributed greatly towards our knowledge of the relationship between matter and energy, and of the structure of the nucleus.



Ernest Walton first split a nucleus in 1932 – a year that deserves recognition for its achievements, says Kevin McCarthy

That year also saw the construction of one of the first particle accelerators by Irish physicist Ernest Walton and Englishman John Cockcroft, which they then used to bombard lithium nuclei with a beam of high speed protons. They thereby achieved the first artificial splitting of a nucleus as well as verifying Albert Einstein's $E = mc^2$ equation by experiment for the first time. In February, James Chadwick made his first observations of the latest subatomic particle to be discovered – the neutron. In August, the world of antimatter opened up when Carl Anderson discovered the positron.

These three great discoveries, combined with other achievements such as the Kennedy-Thorndike demonstration of time dilation and John von Neumann's work on quantum mechanics, show us that the 1930s wasn't as dismal a decade as many seem to believe!
Kevin P McCarthy, Co Kerry

When hunger strikes...

Never mind earworm... I have a tasteworm (or maybe that's a biblioworm?). Whenever I read a copy of *Unlikely Stories, Mostly* by Alisdair Gray, I can taste yoghurt-flavoured Ritter Sport chocolate, which I was eating the first time that I read it.
Andy Northall

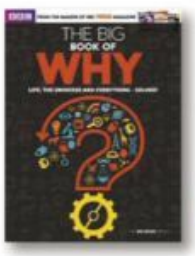


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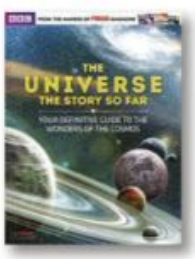


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PHYSICS

THE DAWN OF A NEW ERA

The detection of gravitational waves will give us a fresh perspective on the Universe



Gravitational waves – ripples in space-time predicted by Einstein's General Theory of Relativity – have finally been detected

PHOTO: SCIENCE PHOTO LIBRARY

It looks like the 2016 Nobel Prize in Physics already has a frontrunner: a team at LIGO has directly detected gravitational waves for the first time, 100 years after they were predicted by Albert Einstein's General Theory of Relativity.



A technician inspects one of the LIGO detector's laser-reflecting mirrors for dust particles or any other contaminants

Gravitational waves are ripples in the fabric of space-time generated by violent events such as the collision of massive objects like black holes. They travel across the Universe stretching and squeezing space-time as they go. However, their effect is so weak that even Einstein doubted we would ever be able to detect them.

"Our observation of gravitational waves accomplishes an ambitious goal set out over five decades ago to directly detect this elusive phenomenon and better understand the Universe, and, fittingly, fulfills Einstein's legacy on the 100th anniversary of his General Theory," said LIGO executive director David H Reitze.

The waves observed by the team were generated by the collision of two black holes, about 29 and 36 times the mass of the Sun, which occurred 1.3 billion light-years away. As gravitational waves travel at the speed of light, this means they have taken 1.3 billion years to reach Earth.

The results will open up future opportunities to learn more about the nature of black holes, neutron stars and other astronomical bodies, and to look deeper into the Universe.

"With this discovery, we humans are embarking on a marvellous new quest," said LIGO co-founder Kip Thorne. "The quest to explore the warped side of the Universe – objects and phenomena that are made from warped space-time. Colliding black holes and gravitational waves are our first beautiful examples."

COMMENT

LORD MARTIN REES ASTRONOMER ROYAL

How big a deal is this discovery?
It's one of the great discoveries of the decade, up there with the detection of the Higgs particle, which caused huge razzmatazz three years ago. The Higgs particle was a capstone to the standard model of particle physics, developed over several decades. Likewise, gravitational waves, vibrations in the fabric of space itself, are a distinctive consequence of Einstein's General Relativity.

Why has it taken us so long to detect them?
The problem with gravitational waves is that their detection requires large, expensive and amazingly sensitive instruments. In the LIGO detectors, intense laser beams are projected along 4km-long pipes and reflected from mirrors at each end. By analysing the light beams, it's possible to detect jitter in the distance between the mirrors, as 'space' expands and contracts. The amplitude is exceedingly small: tens of millions of times smaller than the size of a single atom.

What can we learn in the future from 'listening' to gravitational waves?
What is so exciting about the LIGO event is that the form of the 'chirp' exactly matches what was computed on the assumption that General Relativity is correct. So it's given us firmer vindication of General Relativity than we've had from other evidence. This initial detection will stimulate wider efforts to exploit this fundamentally new kind of astronomy, probing the dynamics of space itself.

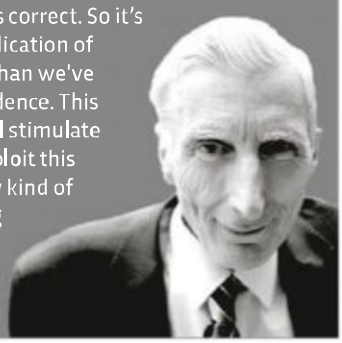


PHOTO: CALTECH

SPACE

Thirsty Earth slows sea level rise

Climate change is turning the Earth into a giant sponge. NASA scientists have found that while glaciers and ice sheets are continuing to melt, changes in climate over the past decade have caused the Earth to soak up an extra 3.2 trillion tons of water, slowing the rate of sea level rise by about 20 per cent.

The discovery was made with NASA's Gravity Recovery and Climate Experiment (GRACE), two satellites which can detect changes in Earth's gravitational pull due to changes in the amount of water on the planet's surface.

Vast amounts of water continually evaporate from the oceans, fall as rain or snow, and then run back into the oceans. "We always assumed that our increased reliance on groundwater for irrigation and consumption was resulting in a net transfer of water from the land to the ocean," said lead researcher JT Reager. "What we didn't realise is that over the past decade, changes in the global water cycle more than offset the losses that occurred."



Sea level rise is occurring more slowly than was predicted

PHOTOS: GETTY, ISTOCK

IN NUMBERS

80
MILLION

The number of microbes transferred during a 10-second kiss, as measured by Dutch researchers.

1
Petabyte

That's a 1 followed by 15 zeroes. The Salk Institute in California reckons that's how much information the human brain can store. It's the equivalent of 212,765 DVDs.

380
attoseconds

380 million-million-millionths of a second was the duration of the shortest ever flash of visible light, produced at Germany's Max Planck Institute.

BIOLOGY

THE SECRET OF LONGER LIFE

It seems having a bit of a spring clean can leave you feeling like a spring chicken. Researchers at Mayo Clinic in Minnesota have found that flushing old cells out of mice extended their lifespans by 17 to 35 per cent, the equivalent of extending a human life from 80 to more than 100 years. The treated mice also looked younger and showed less age-related damage in their muscles and kidneys.

The technique is based on removing so-called senescent cells – cells that have stopped dividing and are no longer needed by the body – using an otherwise harmless drug.

"Senescent cells that accumulate with ageing are largely bad, do bad things to your organs and tissues, and therefore shorten your life but also the healthy phase of your life," said researcher Jan van Deursen. "Since you can eliminate the cells without negative side effects, it seems like therapies that will mimic our findings, either the genetic method that we used to eliminate the cells or drugs or other compounds that can eliminate senescent cells, would be useful for therapies against age-related disabilities, diseases or conditions."



"I'm three years old, you know... and I've still got all my own teeth!"



MEDICINE

DOCTORS IMPLANT 3D-PRINTED 'LIVING' BODY PARTS INTO RATS

This human-sized ear was 3D-printed and then implanted under the skin of a mouse

Gentlemen, we can rebuild him! A team at the Wake Forest Institute for Regenerative Medicine in North Carolina has printed living body parts and implanted them into host animals.

Dubbed ITOP, or Integrated Tissue and Organ Printing, the system has been used successfully to print ear, bone and muscle structures that matured into functioning tissue after being implanted in rats and mice. Although the technology has so far only been tested in animals, the tissues created were of an appropriate size and structure to be used in human subjects, the researchers say.

"This novel tissue and organ printer is an important advance in our quest to make replacement tissue for patients," said Anthony Atala, director of the Institute and senior author of the paper detailing the research, which appeared in the journal *Nature Biotechnology* in February. "It can be used to fabricate stable, human-scale tissue of any shape. With further development, this technology could potentially be used to print living tissue and organ structures for surgical implantation."

The system uses 3D printing technology to deposit layers of biodegradable, plastic-like materials to form the basic framework of the desired tissue. It then fills this in with water-based gels containing living cells that develop into functioning tissue.

So far the team has printed human-sized ears and implanted them under the skin of mice, as well as muscle tissue and human jawbone fragments which they implanted in rats. In all cases, the implants were successfully integrated into the host animals and quickly began to develop networks of nerves and blood vessels.

The ITOP system may one day be able to use data from CT and MRI scans to tailor-make tissue for implant. For example, if a patient was missing an ear the system could be used to print and implant an exact replica of the original.

THEY DID WHAT?!

'Paranoia' triggered in ravens

What did they do?
Scientists investigating animal cognition at the University of Vienna encouraged ravens to hide food next to a box with a peephole in it, linked up to a speaker playing the calls of other ravens.

What did they find?
When the peephole was open, the ravens believed other birds could see their actions and would go to greater lengths to stash their food, even though they couldn't actually see another bird watching them. When the peephole was closed they'd hide the food in a more casual manner.



Why did they do that?
The team is trying to determine whether ravens possess a 'theory of mind'. If so, this means that they are able to imagine experiencing thoughts and emotions felt by other animals – a skill that is widely regarded as a sign of higher levels of intelligence.

Corvids – crows, ravens, magpies and jays – are believed to be the most intelligent bird family

PHOTO: WAKE FOREST INSTITUTE ILLUSTRATION: JAMES OLSTEIN

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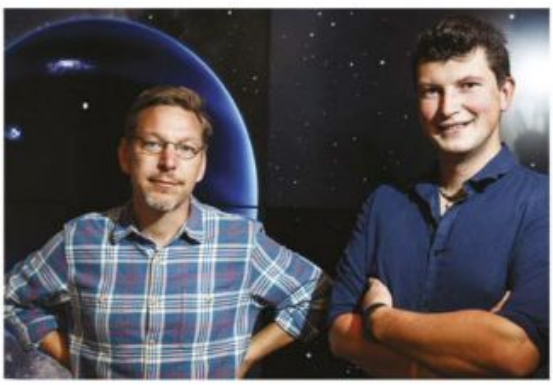
BEHIND THE HEADLINES

"I wouldn't say it's a discovery yet. They've found strong evidence of gravitational disturbances on some of the furthest objects in the Solar System"

PLANET NINE

Could there be a huge ninth planet in the Solar System? We asked Dr Francisco Diego, senior teaching fellow in UCL's Department of Physics and Astronomy, whether there is something out there...

Planetary scientists Konstantin Batygin and Mike Brown of Caltech think there could be a ninth planet in the Solar System. How did they make this discovery?
I wouldn't say it's a discovery yet. They've found strong evidence of gravitational disturbances on some of the furthest objects in the Solar System. The disturbances may be caused by an object with around 10 times the mass of Earth – more or less the size and mass of Neptune. Large bodies beyond Neptune have been hypothesised since the 1980s. There were suspicions of something there but it was never confirmed. Positive confirmation would be to take a picture of Planet Nine, and that would be extremely difficult.

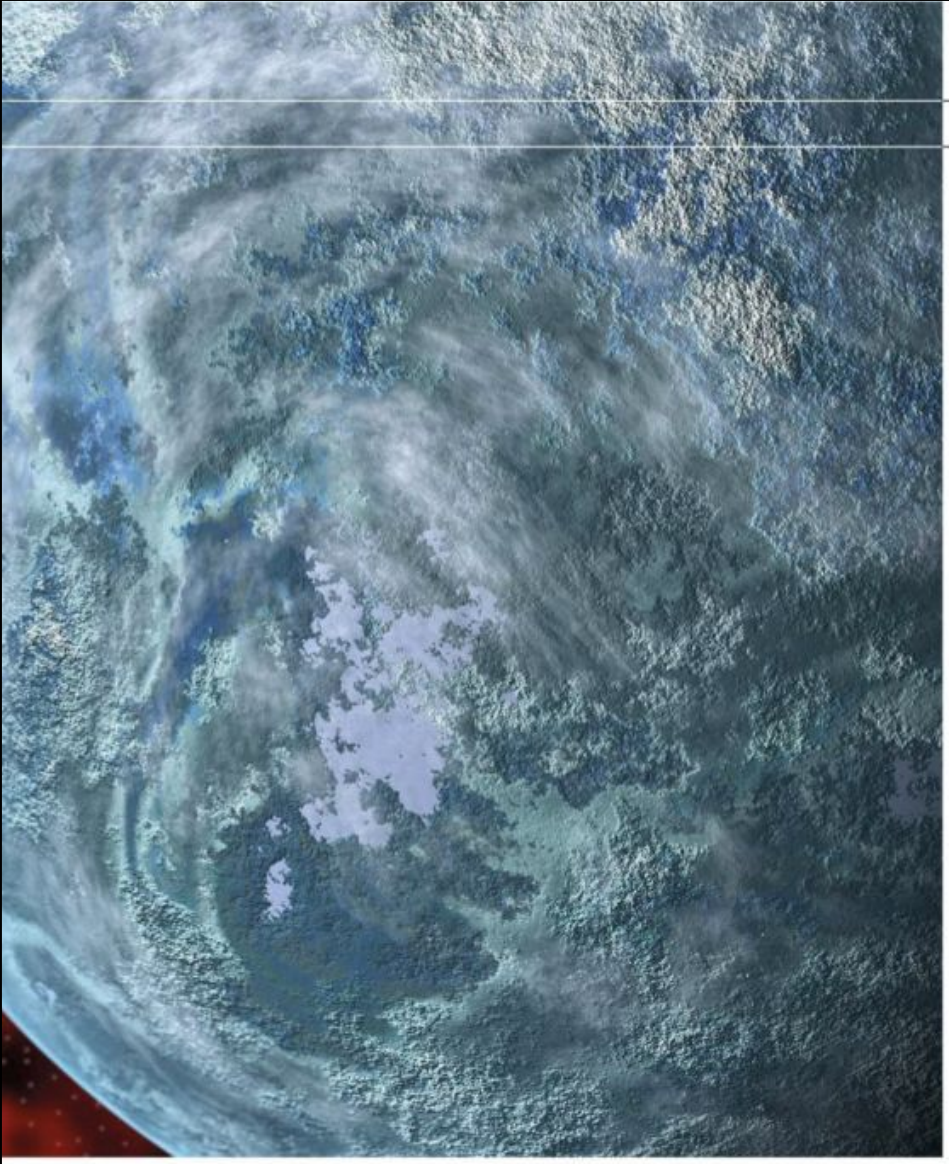


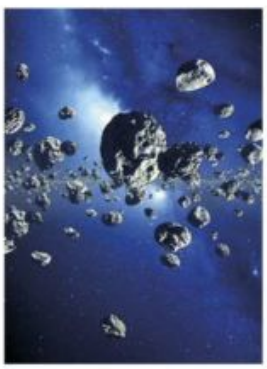
RIGHT: Mike Brown (left) and Konstantin Batygin believe there could be a ninth planet in the Solar System

Why would it be so difficult?
Because it's so far away. Neptune is the furthest proper planet and is 30 times further away from the Sun than Earth [from the Sun to Earth is one astronomical unit (AU)]. From there up to 100 AU is the Kuiper Belt containing Pluto and the other 'trans-Neptunian objects'. Their orbits are extremely tilted and elliptical – they go very far away, come a bit closer and then go far away again. This is the main reason why they're not considered proper planets, because their orbits are different to the orbits of the other planets. 'Planet Nine' is expected to be at a mean distance of 700 AU, in a region between the Kuiper Belt and the Oort Cloud, which extends for thousands of AUs and is where most comets originate.

How could it be done?
There are plans to use the largest telescopes in the world, like the Keck or Subaru, on top of the Mauna Kea volcano in Hawaii. But even taking pictures of Pluto using the New Horizons spacecraft was a major achievement. Pluto is 40

PHOTOS: CALTECH/ R HURT/ IPAC, GETTY, SCIENCE PHOTO LIBRARY





TOP: There is no evidence for what Planet Nine might look like – this visualisation represents exoplanet Kepler 20f

ABOVE: The Kuiper Belt lies beyond Neptune's orbit and contains dwarf planets along with various other bodies

ILLUSTRATION: JAMES OLSTEIN

times farther away from the Sun than the Earth, and the light that illuminates Pluto's landscape is almost zero. Now translate that to Planet Nine, which is about 20 times further away.

We don't know exactly where Planet Nine is, and it's moving extremely slowly. The information we have is that it may take 20,000 years to go around the Sun. In other words, you have something that looks like a very faint star in the sky, and in order to see it moving you'd have to wait a long time. You'd need to dedicate a lot of telescope time to scanning the sky to this low level of brightness, and time on these telescopes is very expensive.

So it could be years before we know for sure?
Yes, unless they find it by chance. But as time goes by, astronomers will gather more information on disturbances on other objects, and this may pinpoint it more accurately. Neptune was found by the disturbances it made to the position of Uranus. Its position was predicted quite accurately by Urbain Le Verrier and John Couch Adams. Astronomers pointed telescopes at it and it was found in 1846. The same could happen again with Planet Nine but the challenge is far bigger than it was over a century ago.



ODONTOPHOBES

Fear of the dentist stopping you from getting your toothache sorted? Researchers at the University of São Paulo have come up with a way for dentists to administer anaesthetic using a small electric current instead of a needle. Now, lie back and say ahhh...

DOG OWNERS

Mutts might have won the battle between cats and dogs. Following research that appears to show that dogs love their owners more than cats do, a study carried out by New York's Manhattanville College suggests dog owners are happier, more satisfied and less neurotic than cat owners.

GOOD MONTH

BAD MONTH

GYM BUNNIES

Gym trips might make it harder to lose weight, according to research by Hunter College, New York. The study found that our bodies adapt to the demands of exercise by lowering our resting metabolisms. While a lunchtime run may burn calories, your body responds by clinging on to the calories left in your body for the rest of the day.

MEN

The female hormone oestrogen may help fight off infections of the flu virus, according to research at Johns Hopkins University in the US. The study indicates there may be a basis to man flu after all...



WHAT WE LEARNED THIS MONTH

PROTECTION ENCOURAGES RECKLESSNESS

Recent research suggests safety kit may increase the urge to take risks. Volunteers at the University of Bath were asked to inflate a virtual balloon as much as possible without bursting it. Some were given a cycling helmet to wear during the task; those that did were more likely to fill the balloon for longer.

OPACITY IS NO GUIDE TO DENSITY

Data from NASA's Cassini mission shows that although the opacity of Saturn's B ring varies, the amount of material it contains is almost uniform throughout.

VENUS FLYTRAPS CAN COUNT

Researchers at Germany's Universität Würzburg mimicked an insect landing on the carnivorous plants and were able to show that one touch didn't trigger the trap. Only after a second touch would the plant close its jaws around the insect.

MOON LANDING FAKE IN FOUR YEARS

According to Dr David Grimes of Oxford University, the number of people required to fake the first Moon landing would mean the plot would have been exposed within four years.

MEDICINE

QUANTUM DOTS TO COMBAT DRUG-RESISTANT BACTERIA

Tiny light-activated semiconductors could be used in the fight against infections such as E. coli and salmonella

Quantum dots – tiny flecks of semiconducting materials that react to light – may solve the growing problem of drug-resistant bacteria, according to researchers at the University of Colorado Boulder.

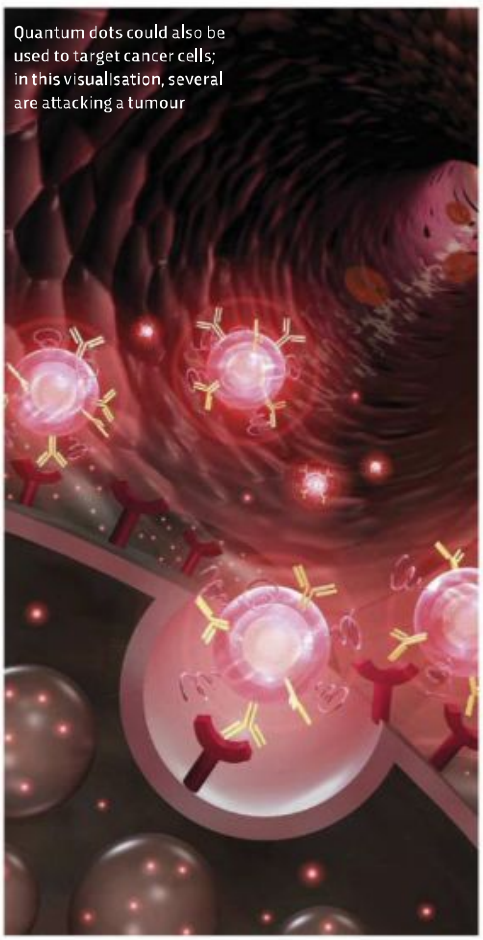
Infections such as E. coli, staphylococcus and salmonella, which are contracted by two million people each year, are becoming harder to treat. This is because the bacteria that cause them are adapting to become immune to antibiotic drugs.

The scientists, based at the Department of Chemical and Biological Engineering, have managed to create light-activated therapeutic nanoparticles – quantum dots – that are able to destroy 92 per cent of drug-resistant bacteria in experiments. The quantum dots are made from the semiconductor cadmium telluride – a material that can conduct electricity under certain conditions – and are 20,000 times smaller than the width of a human hair. The dots are activated by light, which triggers a chemical reaction to break down the bacteria. And as the quantum dots are so small, they can be easily absorbed by the invading bacteria.

"By shrinking these semiconductors down to the nanoscale, we're able to create highly specific interactions within the cellular environment that only target the infection," said Prashant Nagpal, a senior author of the study.

There have been attempts at using nanoparticles made from metals, including gold and silver, to fight drug-resistant bacteria, but these were found to damage the cells surrounding the bacteria indiscriminately. The semiconductor quantum dots, however, target the bacteria specifically.

More importantly, the quantum dots can be altered so that they remain effective even if the bacteria adapts to this form of treatment.



Quantum dots could also be used to target cancer cells; in this visualisation, several are attacking a tumour



Salmonella bacteria (red) can cause severe fever, vomiting and diarrhoea

PHOTOS: GETTY, SCIENCE PHOTO LIBRARY, WIKIPEDIA



TARDIGRADES

NATURE'S TOUGHEST COOKIE

Bear Grylls and cockroaches have built reputations on their ability to survive in harsh conditions, but they're lightweights compared to tardigrades. Despite growing to a maximum of 1.5mm in length, these tiny creatures are phenomenally tough

SPACE ADVENTURERS

Dehydrated tardigrades were exposed to the vacuum of space while aboard a European Space Agency satellite in 2007. Many of the creatures were successfully rehydrated and brought back to life after returning to Earth 10 days later.

SEA FARERS

In June 2000, various species of tardigrade were discovered living in the Gulf of Mexico at depths between 625m and 3,159m. Studies have shown the creatures are able to withstand pressures of up to 87,022psi.

POLAR EXPLORERS

Absolute zero holds no fear for tardigrades. Back in the 1920s, Gilbert Franz Rahm demonstrated this by plunging them into liquid helium at -272°C for almost half an hour. He also submerged another group in water heated to 151°C for 15 minutes.

NUCLEAR SURVIVORS

Tardigrades are able to tolerate doses of ionising radiation 1,000 times higher than what would be lethal for a human. They can even produce viable offspring after exposure.

BIOLOGY

Woken after a 31-year sleep



A splash of water, a petri dish and a few days was all it took for scientists at Japan's National Institute for Polar Research (NIPR) to revive a pair of tardigrades that had been frozen for more than three decades. The microscopic creatures, commonly known as water bears, were recovered from a moss sample collected in Antarctica in November 1983. The sample was stored at -20°C in order to preserve it until it was finally defrosted in May last year, when the presence of the tardigrades, nicknamed 'Sleeping Beauty 1' and 'Sleeping Beauty 2', was spotted.

"Sleeping Beauty 1 first showed slight movement in its fourth pair of legs on the first day after rehydration," reported the NIPR scientists. "Sleeping Beauty 1 started to slowly crawl on the surface of the petri dish on day nine and started to eat the algal food provided on day 13."

Sleeping Beauty 2 only survived for 20 days after being revived, but Sleeping Beauty 1 was able to begin developing and laying eggs within three weeks.

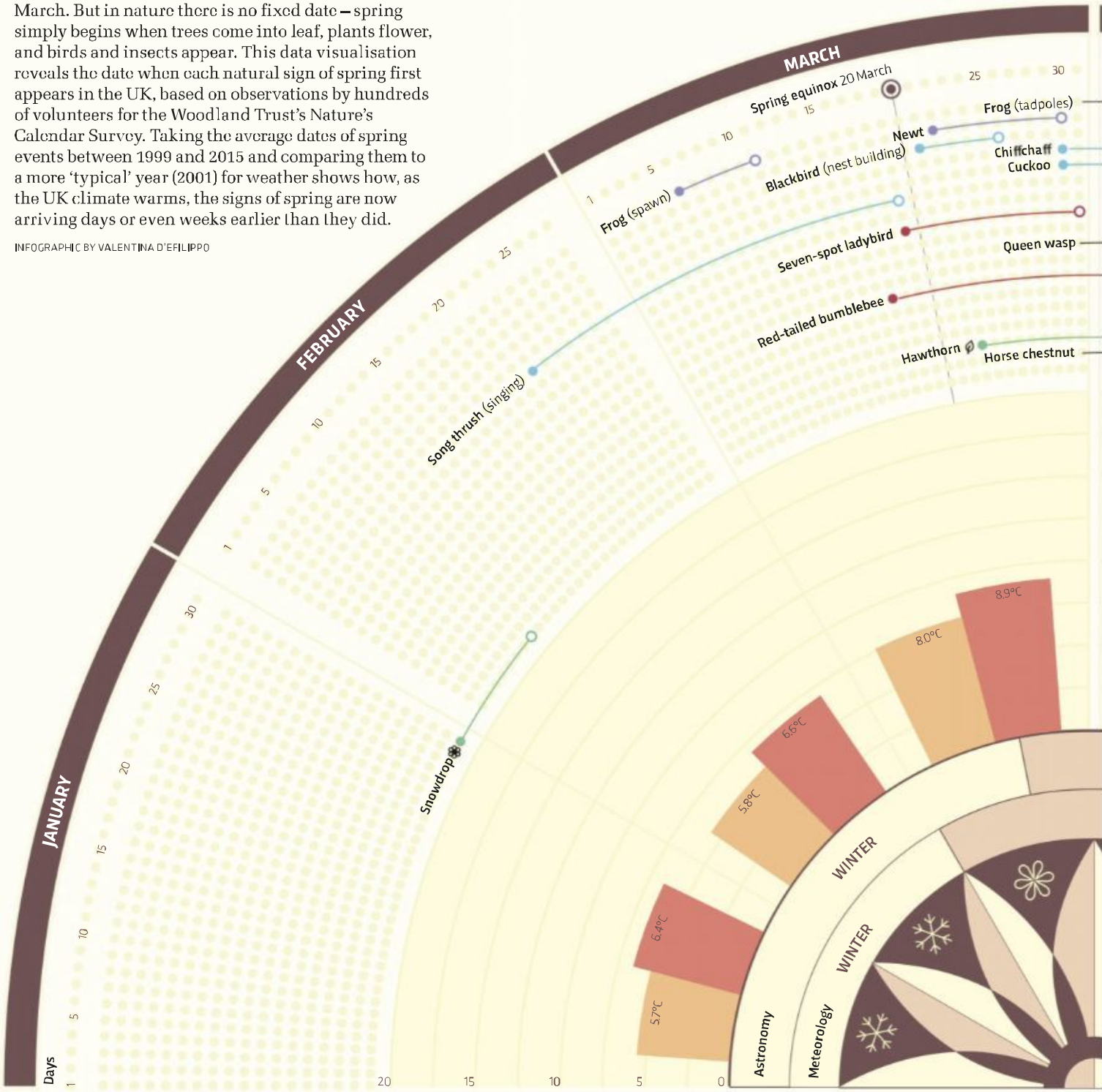
The robust creatures were able to endure the prolonged cold storage by entering a state of extreme hibernation called cytobiosis. A tardigrade's metabolism slows to just 0.01 per cent of its normal rate while in this state. It also dehydrates itself and replaces water in its cells with the sugar glycerol to guard against cell damage during freezing.

It's hoped that investigating cytobiosis in the tardigrade will lead to improvements in our ability to preserve the cell integrity of frozen tissue samples.

WHEN DOES SPRING BEGIN?

The answer depends on who you ask. A meteorologist would say 1 March. An astronomer would answer 20 March. But in nature there is no fixed date – spring simply begins when trees come into leaf, plants flower, and birds and insects appear. This data visualisation reveals the date when each natural sign of spring first appears in the UK, based on observations by hundreds of volunteers for the Woodland Trust's Nature's Calendar Survey. Taking the average dates of spring events between 1999 and 2015 and comparing them to a more 'typical' year (2001) for weather shows how, as the UK climate warms, the signs of spring are now arriving days or even weeks earlier than they did.

INFOGRAPHIC BY VALENTINA D'EFILIPPO



Calendar of natural events
First recorded appearance of species or event

Highest daytime temperature
UK average for month (°C)

Definitions of spring
Astronomical and meteorological

Calendar of natural events

Average 1999–2015 — 2001

- Amphibians
- Birds
- Insects
- Plants
- first leaf
- first flower

Why 2001? We sometimes lack consistent data on spring events from the years prior to 1999, so 2001 is often used by scientists as a benchmark for comparison instead. This is because temperatures that year were close to the 1961–1990 average for the UK and so fairly normal by historical standards, though still feel cool compared to recent years.

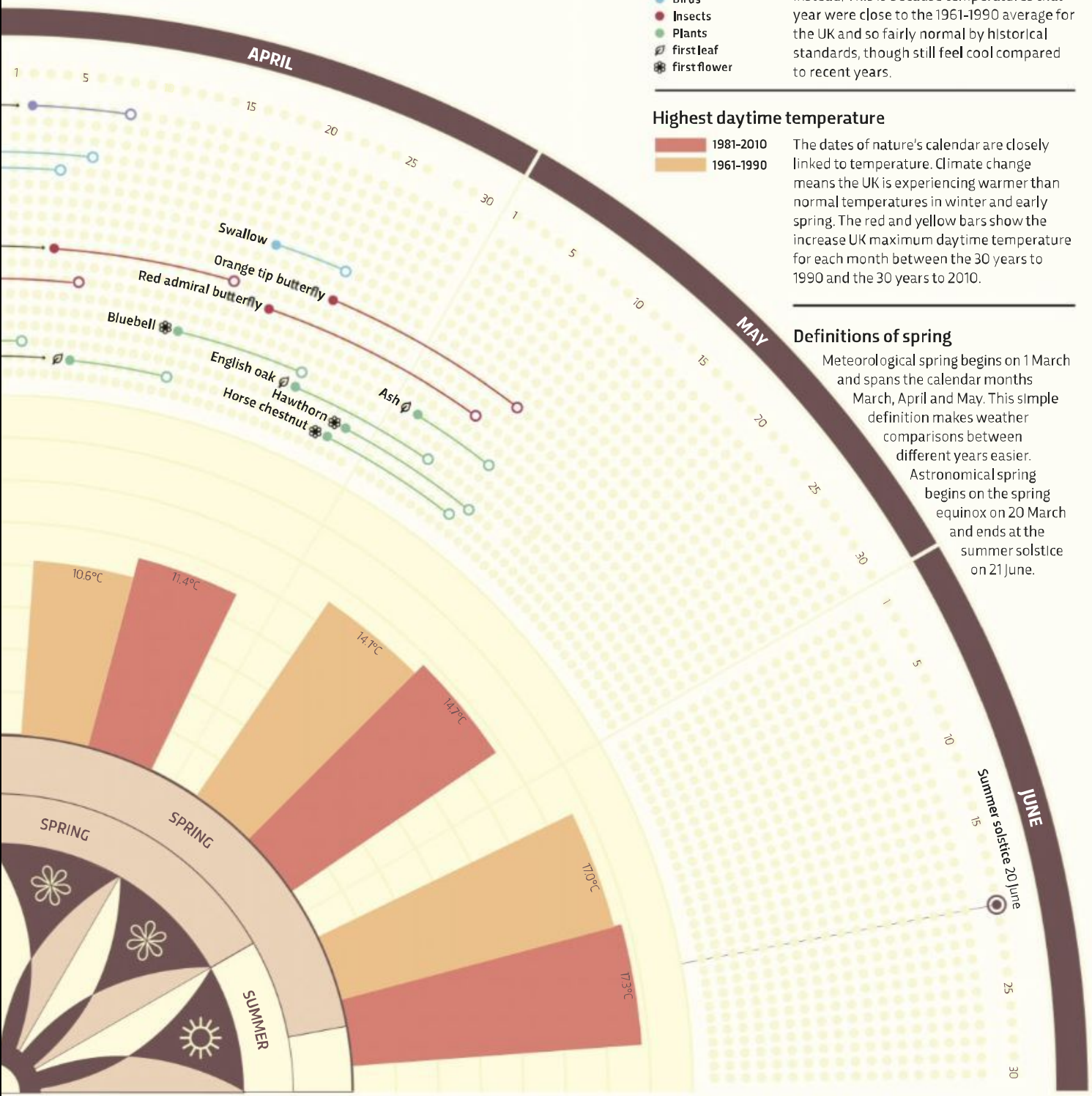
Highest daytime temperature

- 1981–2010
- 1961–1990

The dates of nature's calendar are closely linked to temperature. Climate change means the UK is experiencing warmer than normal temperatures in winter and early spring. The red and yellow bars show the increase UK maximum daytime temperature for each month between the 30 years to 1990 and the 30 years to 2010.

Definitions of spring

Meteorological spring begins on 1 March and spans the calendar months March, April and May. This simple definition makes weather comparisons between different years easier. Astronomical spring begins on the spring equinox on 20 March and ends at the summer solstice on 21 June.



DATA SOURCES: WOODLAND TRUST NATURE'S CALENDAR SURVEY, WWW.NATURESCALENDAR.ORG.UK / UK MET OFFICE

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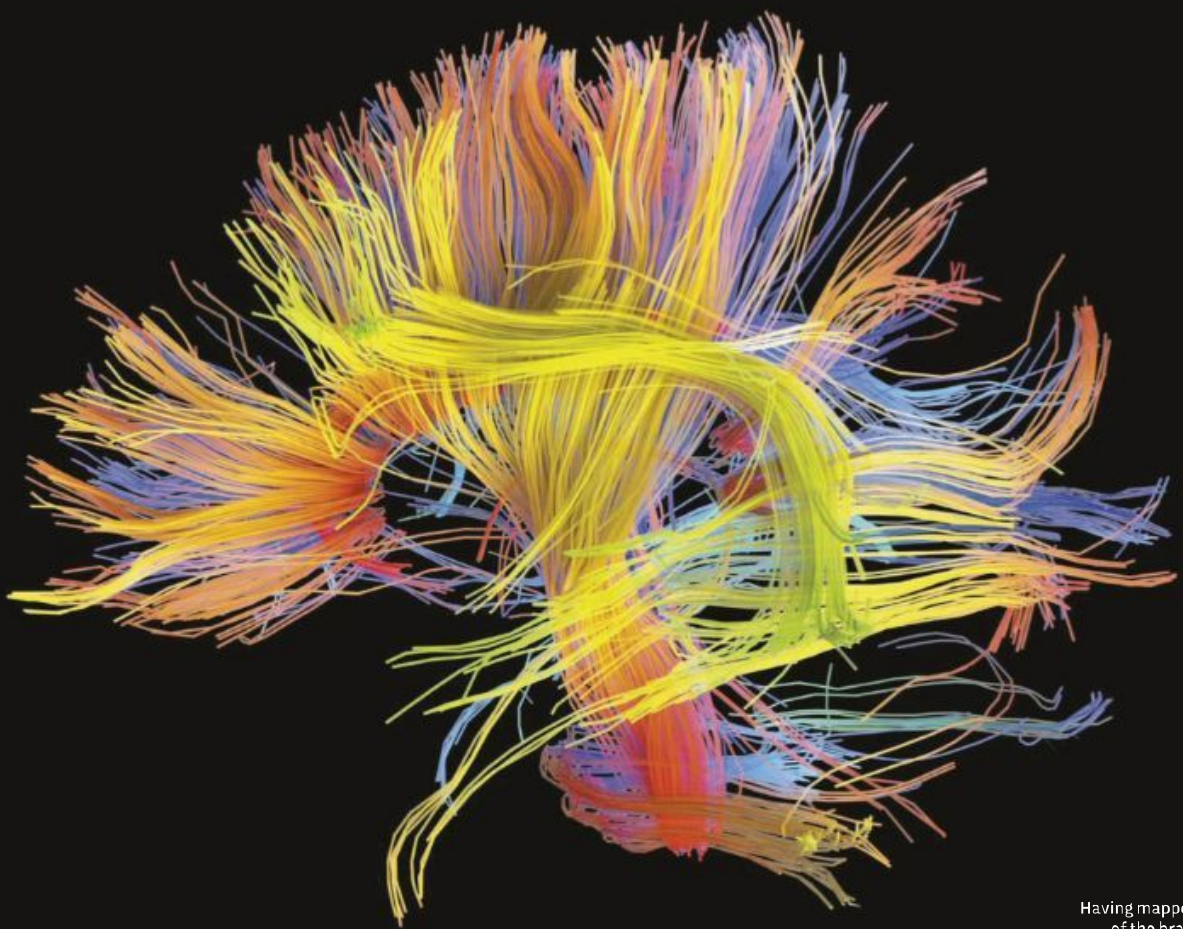
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INNOVATIONS

PREPARE YOURSELF FOR TOMORROW

MARCH 2016

EDITED BY RUSSELL DEEKS



Having mapped the neurons of the brain, DARPA now plans to build an interface that will interpret the organ's electrical and chemical signals

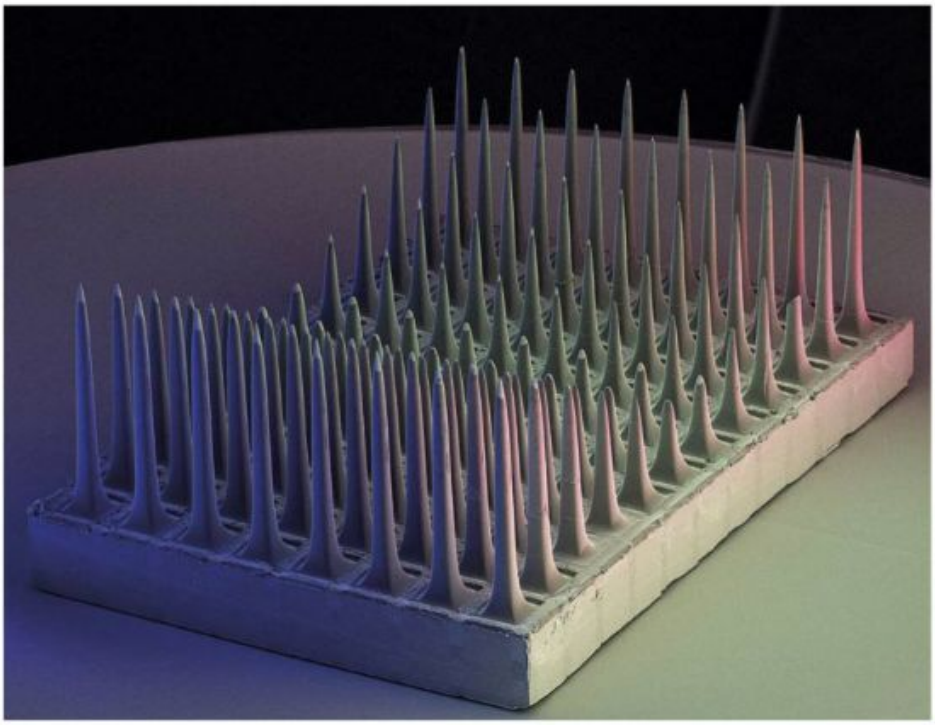
PHOTO: GETTY

OPERATION MIND CONTROL

DARPA is developing a brain-computer interface

The US's 'mad science' wing DARPA (the Defense Advanced Research Projects Agency) is working on an implantable brain device that it hopes will let us control machines with our minds.

The 'wetware' project comes under the auspices of DARPA's Neural Engineering System Design (NESD) programme, and would take the shape of a small disc no more than a few millimetres thick. The device would monitor chemical signals in the brain and convert them into a series of digital pulses, and vice



DARPA's neural interface chip allows direct communication with the brain

versa. The technology involved isn't exactly new: laboratories around the world have been working to develop BMIs for quite a few years now. Indeed, some medical applications of the technology are already in use. But DARPA's project has two advantages over existing systems. First, the 'resolution' is much better – it's suggested that it would connect to up to a million individual neurons (brain cells), whereas existing devices have only around 100 channels, each carrying an aggregate signal from tens of thousands of neurons. This means that people with prosthetic limbs, for instance, would be able to control their devices much more accurately, while users of 'bionic' visual or cochlear implants would receive a much clearer incoming signal from their device.

Second, it's being developed by the US military, and forms part of the BRAIN Initiative – an ambitious long-term project introduced by President Obama in 2013 that aims to do for our understanding of the brain what the Human Genome Project did for our knowledge of genetics. This means there's never going to be any shortage of research and development funding – DARPA's already talking about $60m of investment over the next four years.

NESD programme manager Phillip Alvelda said in a statement to the press: "Today's best brain-computer interface systems are like two supercomputers trying to talk to each other using an old 300-baud modem. Imagine what will become possible when we upgrade our tools to really open the channel between the human brain and modern electronics."

"IMAGINE WHAT WILL BECOME POSSIBLE WHEN WE OPEN THE CHANNEL BETWEEN THE BRAIN AND ELECTRONICS"

It should be stressed that the NESD programme is very much a work-in-progress, and that we won't see a device of the kind DARPA is envisaging coming into real-world use any time soon. As DARPA freely admits, there are many advances still required in neuroscience, synthetic biology, photonics, data compression and several other disciplines before the NESD vision becomes reality. But when it does, remember where you read about it first.

NEWS BYTES



GAME OF PHONES

Japanese telecoms giant SoftBank is to open a Tokyo phone shop staffed almost entirely by its Pepper robots. Six Peppers will explain products and take your order – but a real human will be on hand to verify paperwork.

ELECTRIC DREAMS

Local councils across the UK are being given £40m in government funding to build a better infrastructure for electric cars. The Go Ultra Low City Scheme money could be used to build dedicated electric vehicle lanes or install vehicle chargers into streetlights, for instance.

GOING UP

The International Space Elevator Consortium has published a paper in *New Space* saying that current advancements in technology mean the materials needed to create the 100,000km 'rope' for a space elevator will emerge no later than 2030.

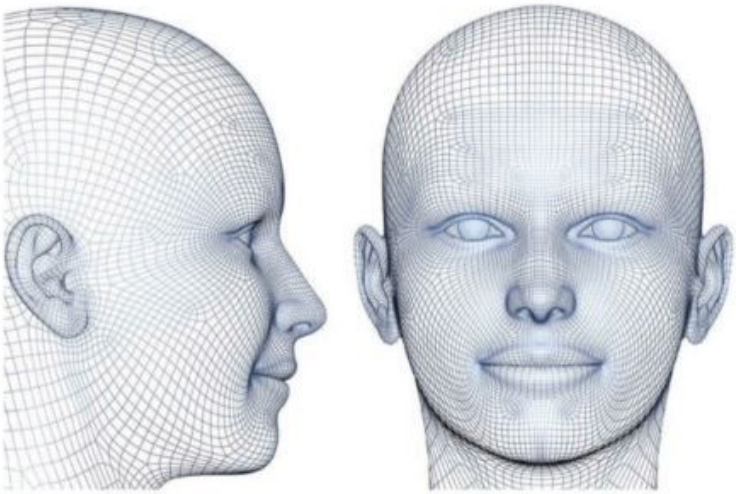


TINY TUNES

Teenage Engineering has expanded its Pocket Operator range of mini synthesisers. Unlike previous models, each of which created just bass, drum or lead sounds, the new PO-20 Arcade, PO-24 Office and PO-28 Robot pack all three sonic elements into one €69 (£50 approx) device.

BRIGHT IDEA

Cheaper solar cells could be on their way thanks to a breakthrough at the École Polytechnique Fédérale de Lausanne in Switzerland. Rather than using perovskite nanoparticles to create solar cells, the team have found a way of reliably manufacturing 'nanowires', which are more efficient.



CRIME

Japanese criminals: now in 3D!

If you get caught breaking the law in Tokyo, be warned: it's not just your mugshot and fingerprints the police will be registering. From April, all 102 police stations in Japan's capital will be equipped with 3D cameras that will create a full 3D rendering of a wrongdoer's head. Tokyo police say the new technology – which has actually been in development since way back in 2001 – will make it much easier to identify known villains in CCTV footage. One policeman told Japanese newspaper *The Asahi Shimbun* that "as we can identify the suspects more quickly and accurately, our arrest rate is expected to become greater."

MEDICINE

A pen that detects cancer

Developed by a team from the University of Washington and several other US universities and hospitals, this handheld device uses 'dual-axis confocal microscopy' to detect cancer cells up to 0.5mm below the surface of tissue. This enables doctors to tell if a tumour is cancerous without the need for a biopsy.

The 'pen' could also find a home in the operating theatre, giving surgeons a clearer indication of when their work is complete. Jonathan Liu, senior author of the paper in the journal *Optics Express* that introduced the device, says: "Surgeons don't have a very good way of knowing when they're done cutting out a tumour. They're using their sense of sight, their sense of touch, pre-operative images of the brain – and oftentimes it's pretty subjective."

The device is expected to start full clinical trials soon.



Could this pen mean the end of biopsies?

PHOTOS: SCIENCE PHOTO LIBRARY X2

SECURITY

Google wants to watch you even more



Nope... wrong password again

Tired of having to type in a code to use your smartphone, and needing to remember dozens of different passwords for online services such as banking? Don't worry – those days could soon be gone. The only *slight* downside is that you'll need to agree to your every movement being monitored by Google 24/7 instead.

Project Abacus is Google's new plan to replace the password. It uses the various sensors in your Android device to measure your walking speed, location, voice patterns, face and other biometric readings. Essentially, the device you're using 'knows' that you're you, and also 'knows' when it's been picked up by someone who *isn't* you. Google's system is said to be up to 10 times more secure than even two-factor authentication, and harder to deceive than a fingerprint sensor.

It's suggested that Abacus – which after all is only marshalling information your phone's already collecting – could be installed on Android devices via a simple software update. That's if it happens at all – it's fair to say reactions to the idea on the blogosphere haven't been *entirely* positive. Not that the wishes of mere serfs count for much, of course...

WANTED!

VIRTUAL INSANITY

ASUS ROG G20CB



The first wave of 'Oculus Rift-ready' PCs – machines that come bundled with an Oculus Rift headset and some VR games – will be hitting stores soon. Asus has three models on offer, including two variants of this spaceship-style desktop, sporting either an Intel i5 chip, NVIDIA 970 graphics card and 512GB solid-state drive; or an i7 chip, NVIDIA 980 graphics card and a 1TB hard drive. If you're on a budget, the lower-specced G11CD is also available at just £725.

£1,000/£1,175, asus.com



GAME ON

8BITDO RETRO CUBE SPEAKER

Hurrah – a Bluetooth speaker built with ageing gamers in mind! The Retro Cube Speaker is styled, as most of you will have noticed, after the controller for the classic NES console. The four-way directional pad that once helped Mario topple Donkey Kong now turns the speaker on and off and controls volume, while four speakers serving up 2 x 1.5W replicate the A/B/X/Y buttons. With eight hours' battery life, it might not be the best-sounding speaker around, but as a talking point it's hard to beat.

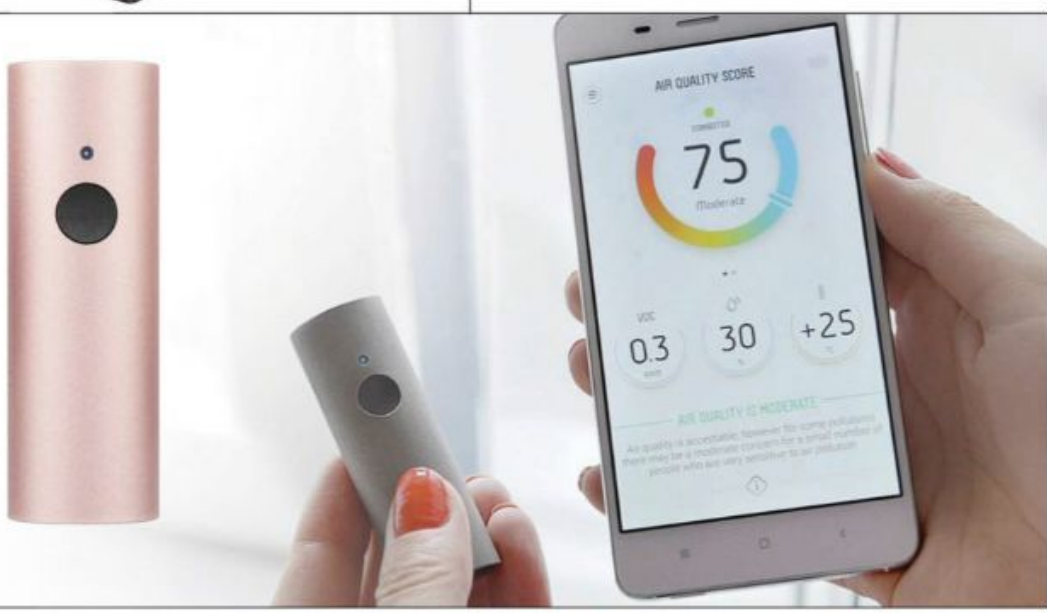
£25, 8bitdo.com

BREATHE EASY

ATMOTUBE

If you've got asthma or allergies, or suffer from a lung condition, air quality can be a serious issue – so here's a portable, wearable device to help you monitor it. Atmotube measures humidity and temperature, along with the levels of 19 common airborne pollutants. It displays the results on your smartphone while also relaying them to a free global air quality map so that others can see what locations they might want to avoid.

$89 (£60 approx), atmotube.com



ROVING CAMERA

LEICA X-U

Tough, high-end camera for OTT antics



High-end manufacturer Leica has long been the choice of many a professional photographer, but there've always been places you might be wary taking several thousand pounds' worth of camera. Which is why Leica has now introduced its toughest ever model, the X-U. Waterproof to 15m, dustproof and shockproof, with a fixed 23mm lens and shooting both stills and HD video, this is the Leica you can take snowboarding or diving without worrying.

£2,400, leica-camera.com



WIN WHEN YOU'RE SWINGING

GARMIN TRUSWING

Want to improve your golf game? This new swing sensor from Garmin could be just the thing you need. The 28g, 6.7cm-long device clips onto your golf club, measures your swing and feeds data on your club path, face angle, shaft angle, trajectory and swing tempo either to your Garmin Approach watch (sold separately) or to the Garmin Connect app on your smartphone. The device will run for 12 hours on a single charge, and it's waterproof so you can use it come rain or shine.

£129.99, garmin.com

ABSOLUTELY BARKING

CHIP ROBOT DOG

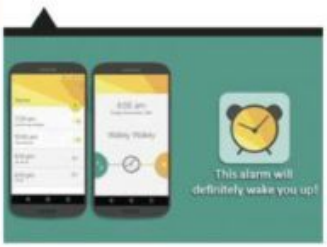
Remember the robot dog craze of the late 90s? Well, robotics and AI have moved on considerably since then – and so have robot dogs. CHiP can play fetch, chase and catch, learn tricks and recognise his owners. He needs feeding via a mobile app twice a day and will remind you when he's missed his dinner – and take himself off to 'bed' when it's time to recharge his batteries. He's also, you may have noticed, not *entirely* uncute…

$179 (£120 approx), chipk9.com

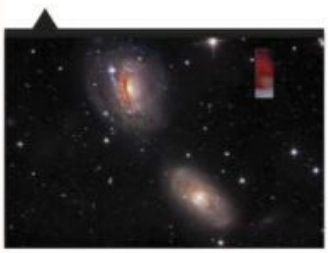


APP FEED

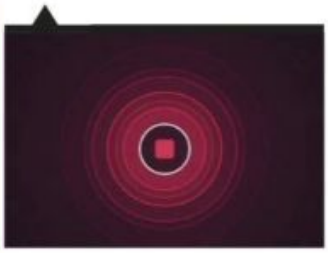
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Free, Android



Newsfusion
Newsfusion brings together news from NASA, ESA and academia to keep you up to speed with all things space.
Free, iOS/Android



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HOW WE'LL
KEEP THE
LIGHTS ON

Five years on from the meltdown at the Fukushima Daiichi power plant, nuclear energy remains controversial. But with fossil fuels dwindling, can we afford to ignore nuclear energy forever?

WORDS: DUNCAN GEERE



The accident at Fukushima destroyed Japan's faith in nuclear power

On 11 March 2011, the future became the past. A magnitude 9.0 earthquake striking about 70km off the Pacific coast of Japan sent a huge surge of water towards the Fukushima Daiichi nuclear power plant. The control room tried to shut it down, but water damage caused the diesel generators to fail, preventing coolant systems from operating. Three of the reactors in the plant suffered core meltdowns, with a series of accompanying explosions and the release of large amounts of radioactive material into the environment. It was a decisive moment in the history of energy, turning a generation against nuclear power.

Five years on and the effects of the disaster are still apparent: small amounts of radiation continue to leak in to the Pacific Ocean and tonnes of waste and debris remain to be cleared.

Rewind to 1946: The Atomic Age. Following the development of nuclear energy alongside nuclear weapons in WWII, newspapers, magazines and research papers were filled with bold predictions about a utopian future powered by the energy of the atom. David Lilienthal, chairman of the US Atomic Energy Commission, was among the most enthusiastic. "Atomic energy is not simply a search for new energy, but more significantly a beginning of human history in which faith in knowledge can vitalise man's whole life," he said.

Slowly, however, public perception of nuclear energy began to change. During the 1960s and 1970s, it gradually slipped in popularity. The 1979 nuclear meltdown at Pennsylvania's Three Mile Island, combined with the growing environmental movement and the arms race of the Cold War, turned more and more people against the technology. The wave of public opposition crested in 1986 following the Chernobyl accident. Less than 30 years after its grand arrival, the nuclear dream was on life support.

"The Chernobyl accident almost brought to a halt the deployment of nuclear power plants," explains Nikolaus Muellner, head of the International Nuclear Risk Assessment Group, an independent body of nuclear safety experts. "The first generation of plants was constructed and built in the 50s and 60s, then the second generation was built in the 70s and 80s. Then you have a gap." During that gap, researchers came up with a 'third generation' reactor design that was significantly safer – it could handle an accident like Chernobyl without releasing significant amounts of radioactive material into the environment. But in the face of widespread public opposition, it was impossible to build and test these plants. The nuclear industry was stuck in limbo – it couldn't improve the safety of its plants without building new reactors, but public fears over safety meant that no new reactors could be built.

Then the Fukushima disaster happened. Opposition to nuclear energy, which had faded somewhat over time, turned once more against the technology. Germany pledged to shutter all its reactors by 2022, while Italy held a referendum in which 94 per cent voted against a government plan to build new nuclear plants. In France, where nuclear was successfully sold to the public as a route to energy independence, the president François Hollande announced his intention to reduce the share of energy generated by nuclear. Meanwhile, here in the UK, no new nuclear power stations have been built since 1995, and current plans for energy company EDF to build one at Hinkley Point in Somerset have been met with opposition. So where does that leave nuclear now?

PHOTO: PRESS ASSOCIATION ILLUSTRATOR: MAGIC TORCH

SAFER THAN SOLAR?

Over the last 20 years or so, most Western nations have merely maintained their existing reactors, making incremental safety upgrades to meet regulations. Countries that chose to retain their nuclear plants extended their lifespans, in some cases well beyond their original design specifications. "The reactors were designed for a lifetime of 40 years, and then they got extended to 60 years," says Muellner. "The [older] reactors are going to stay online for a long time, and they dominate the total risk of a nuclear accident." Safety levels, while not necessarily dropping, were certainly not going up. "If you build new plants somewhere, that's an event that will get attention," says Muellner. "But lifespan extension is something which is not perceived." Without building new plants, however, substantial leaps in technology were impossible, and the industry was forced to simply pray that there would never be another major nuclear accident.

But when you look at the raw data, nuclear energy comes out ahead of other options. Futurist and energy researcher Brian Wang ran the numbers shortly after the Fukushima accident back in 2011. He found that when you compare all power sources around the world in terms of energy output, coal and oil are by far the most dangerous, resulting in 100 and 36 deaths per terawatt-hour (TWh) respectively. This is mostly due to the significant air pollution they cause. Nuclear energy, on the other hand, results in just 0.04 deaths per TWh – lower even than renewables like wind and solar. This is because there are dangers involved with mining the materials needed for wind and solar, as well as risk associated with erecting wind turbines and solar panels in dangerous locations. Other studies show similar results.

So is nuclear power safe? That's a matter of definition, says Muellner: "There's a set of rules, they differ around the world, so the word 'safe' means something different in different countries." There are some conventions – almost all safety regulations are based on probability. A plant may, for example, need to be engineered to withstand an earthquake that occurs once every 100,000 years. "But this doesn't mean that an accident cannot happen," says Muellner. "Weird accidents can happen – they have a small probability. But there is still a possibility that severe accidents, including releases, may happen in nuclear power plants."



PHOTOS: GETTY X7







1 The Three Mile Island accident was the worst in the history of US nuclear power
2 The cooling towers of Three Mile Island loomed above the town
3 Protesters at Germany's Gundremmingen nuclear power plant
4 The remains of Chernobyl

PHOTOS: GETTY, SCIENCE PHOTO LIBRARY

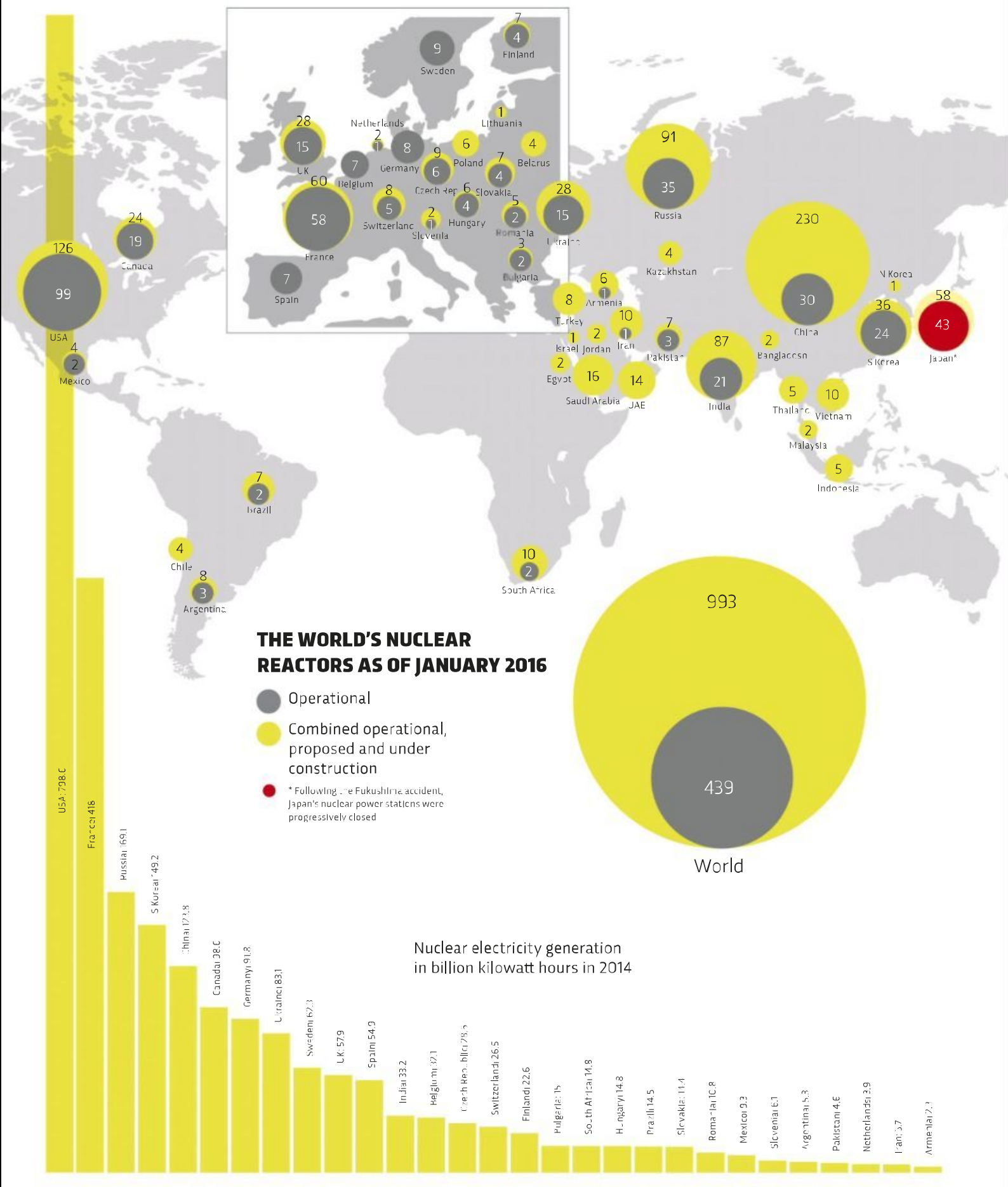
"So, how much is nuclear energy contributing to climate change? An operating nuclear reactor has near-zero carbon emissions, as its only outputs are heat and radioactive waste"



Another problem with this approach is that the probabilities of severe weather events are changing because of climate change. "You can't say for sure that the data you recorded in the last hundred years are going to be valid in the future," Muellner explains. "Currently it's not clear how to handle this. There is the requirement, from, for example, the Western European Nuclear Regulators Association, to take into account your safety analysis for climate change.
But how to do that is currently still under discussion."

So, how much is nuclear energy contributing to climate change? An operating nuclear reactor has near-zero carbon emissions, as its only outputs are heat and radioactive waste. Of course things change slightly when you factor in the construction and decommissioning of the plant, the mining, processing and transportation of its uranium fuel, and the storage of nuclear waste, but the technology still rates well in terms of emissions when compared to coal, oil and gas. "If you don't replace the existing nuclear power stations that we have globally then it makes meeting the objective of having a low carbon power system much much harder," says Ben Caldecott, program director of sustainable finance at the University of Oxford's Smith School.

There is much debate over the role of nuclear power in fighting climate change – in fact there's a profound split in the environmental movement. A group of people that sometimes refer to themselves as 'ecomodernists' reject the environmentalist belief that nuclear power is bad. "Nuclear fission today represents the only present-day zero-carbon technology with the demonstrated ability to meet most, if not all, of the energy demands of a modern economy," reads the *Ecomodernist Manifesto*, a document published by a group of researchers and activists in April 2015. "A new generation of nuclear technologies that are safer and cheaper will likely be necessary for nuclear energy to meet its full potential as a critical climate mitigation technology."



THE WORLD'S NUCLEAR REACTORS AS OF JANUARY 2016

Operational

Combined operational, proposed and under construction

* Following the Fukushima accident, Japan's nuclear power stations were progressively closed

Nuclear electricity generation in billion kilowatt hours in 2014

NEW-LOOK NUCLEAR



ABOVE: Reactors aboard floating nuclear power plants would be easy to cool, but there could be an added risk of sinking

PHOTO: MIT

While ecomodernists think that nuclear power could be a useful tool in slowing climate change, more traditional environmental organisations vehemently disagree. "Nuclear power already delivers less energy globally than renewable energy, and the share will continue to decrease in the coming years," Greenpeace writes on its website. "Building enough nuclear power stations to make a meaningful reduction in greenhouse gas emissions would cost trillions of dollars, create tens of thousands of tons of lethal high-level radioactive waste, contribute to further proliferation of nuclear weapons materials, and result in a Chernobyl-scale accident once every decade. Perhaps most significantly, it will squander the resources necessary to implement meaningful climate change solutions."

Those resources are significant. The centralised nature of nuclear power, compared to decentralised renewables, means that finding the cash to pay for new reactors is not easy. "The nuclear power industry is about really big engineering projects that take many years of planning, with designs that must be approved by regulators and take many years to get approval," explains Caldecott. "It just can't compete against decentralised renewable technologies that can be deployed quickly."

A number of new approaches to nuclear energy have been proposed that could solve some of those problems. Despite the scarcity of third-generation reactors around the world, a fourth generation is already on the drawing board. These are able to use far more of the available uranium, making them significantly more economical. Yet they still need major research and development before they can be built, which is a tall order in today's nuclear-averse society. "I personally don't think that we're going to see a large-scale deployment of generation-four reactors any time in the future," says Muellner.

Another potential option is to build thorium-fuelled reactors. Thorium produces far less dangerous waste than conventional nuclear energy and is three times more abundant in the Earth's crust than uranium, although it also has its downsides. It will require significant research and development investment before it could be rolled out, and processing the fuel involves extremely high radiation levels. In a 2012 report into the technology, the *Bulletin Of The Atomic Scientists* journal wrote that thorium would "require too great an investment and provide no clear payoff". Yet there are still some researchers who believe thorium to be the way to go.

Others have proposed that nuclear plants could be located several miles offshore on floating barges like those used in oil and gas drilling. This novel solution would solve three key problems for nuclear power: cooling the reactor; siting it away from residential areas; and resisting tidal waves like the one that submerged Fukushima. It could even be relocated in response to demand. Yet floating nuclear plants are not risk-free. They will be exposed to new problems such as boat collisions, terrorist attacks and sinking.

BRIGHT FUTURE?

"A combination of high upfront costs, stringent safety regulations, difficulties in getting financing, unpopularity with the public, risk of weapons proliferation and rapid development of competing renewables means that building new plants is almost impossible"



1 China is keenly expanding its catalogue of nuclear power plants
2 Changjiang nuclear power plant, seen here under construction, became fully operational at the end of 2015

There is an alternative concept of 'small modular reactors'. These miniature, scaled units are similar to the ones used to power nuclear submarines. These reactors could be deployed and it would be easy to scale them up or down to suit cities of different sizes. These reactors don't require such huge up-front costs, so are much easier to roll out, but aren't significantly cheaper than the big reactors in terms of investment per installed kilowatt. "We may see some of these," says Muellner, "but I'm not sure that they're going to make a difference."

So is nuclear energy likely to be a part of our future? It depends. In China and India, where public opinion plays less of a role in governmental decision-making, officials are aggressively expanding their nuclear output with new, safer, third-generation reactors. China has 29 operating nuclear plants and aims to more than double that figure by 2020, while India has a total of 21 reactors with more than 20 further units planned. "If it's government policy to deploy nuclear power, then it's going to be built," says Muellner.

But in the West, it's not looking good for nuclear energy. A heady combination of high upfront costs, stringent safety regulations, difficulties in getting financing, unpopularity with the public, risk of weapons proliferation and rapid development of competing renewables means that building new plants is almost impossible. Nuclear power is getting squeezed out of the picture by alternative energy technologies that are cheaper, simpler and not so politically toxic. "Basically, everything is tilted in the favour of its [nuclear's] competitors," Caldecott says. "And that tilt will just get steeper and steeper."

Duncan Geere is a freelance science and technology writer who's based in Gothenburg.

DISCOVER MORE

Listen to an episode of *Analysis*, which asks whether we can live without nuclear power, at **bbc.in/1GcJAmK**

Take a tour of Britain's most controversial nuclear facility with physicist Jim Al Khalili in *Britain's Nuclear Secrets: Inside Sellafield*. Download for £1.89 at **store.bbc.com**

PHOTO: GETTY



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WHERE THE WILD THINGS ARE

From DNA trackers to drone spies, the tech that zoologists use today would put James Bond to shame…

WORDS: MATT SWAINE





PHOTO: ALISTAIR HOBDAY

COSMIC CAMERAS

The high-resolution GigaPan camera was initially developed for NASA's Curiosity Mars Rover, to send back breathtaking panaromas of the Red Planet. Now, it's finding a second life in conservation.

A team at Carnegie Mellon University used a GigaPan to monitor 100 albatross nests in the Bass Strait in Tasmania, snapping two panoramic pics a day over a six-month period. The images are so detailed that researchers can zoom in to view each nest, enabling them to identify individual birds and study their breeding patterns. The photos can also be viewed in sequence as a time-lapse movie. See panoramas with your own eyes at **Gigapan.com**



SNOT AT SEA

Drones armed with an array of high-tech sensors and cameras are increasingly being used to monitor wildlife. However, a team of researchers from Ocean Alliance are finding out more than ever about whales by fitting their drones with a simple perspex dish.

When whales breathe out through their blowhole, Ocean Alliance's so-called SnotBot can fly through the cloud of mucus and expelled air to gather biological material on its dish. This is less invasive than the traditional technique of collecting a tissue biopsy with a dart. A 'snot' sample can provide genetic material, as well as data on microbiomes, pregnancy hormones and even traces of pollutants in the water.

"An individual whale may only surface for a matter of minutes," explains Ocean Alliance CEO Iain Kerr. "We might see 30 whales in a day and we would [previously] have been happy if we'd just collected five or six samples. With the drone we can get on the whale much more quickly and that count could go up to 15 samples a day."

The drone also carries a camera, so the scientists can study the whales without spooking them. "We can see whales behaving in ways that we wouldn't get otherwise," Kerr says. "Only recently, we recorded a mother and calf together in an incredibly intimate moment. With a boat, the calf would immediately go underneath the mother and you wouldn't see it at all."



The rhino is sedated before the RAPID device is mounted into its horn

RAPID RESPONSE

In South Africa a rhino is killed every eight hours. With poaching rates increasing by more than 9,000 per cent since 2007, the species are being driven towards extinction.

Trying to monitor poachers across the vast areas of rhino habitat is a mammoth undertaking, but help may be on hand in the form of a combined tracker and security system designed by Chester University's Paul O'Donoghue. Dubbed the Real-time Anti-poaching Device (RAPID), the tracker combines GPS, a heart monitor and video camera mounted in a small hole bored in the rhino's horn. If an animal is killed, the heart rate monitor triggers an alarm alerting rangers to the incident, while the GPS provides them with its exact location. A team of rangers can then be dispatched to the scene by helicopter, leaving poachers little time to harvest the horn.

SIMIAN SOUNDS

Thanks to their speed and general habit of monkeying around, accurately monitoring primate behaviour can be a tall order. The use of camera traps has made things significantly easier, but one team in the rainforest of Taï National Park in Côte d'Ivoire are taking a different tack: they are using acoustic sensors to record the primates' calls.

The researchers developed an algorithm that automatically identifies the calls of three monkey species. They were then able to estimate how many animals were in a given area. It is hoped that the system can be used to allow conservationists to monitor population changes in real time.



"Bizarrely, these wasps don't just work for their own colony, but also for numerous neighbouring colonies"



Tiny RFID tags fitted to tropical wasps have revealed intriguing behaviour about the insects

CARD-CARRYING WASPS

The same RFID technology used in Oyster Cards is being employed by researchers from Bristol University to study the social behaviour of tropical paper wasps. The insects were each fitted with a small RFID tag weighing just 18mg. A tag reader in each colony then monitored when they entered or left the nest. "Bizarrely, these wasps don't just work for their own colony, but also for numerous neighbouring colonies," says researcher Patrick Kennedy. "So we rig up a population of colonies with RFID-antennae and work out social networks showing their movements. My main experiment involves plucking out the queen from certain nests to see if the vagrant wasps take up the sudden opportunity to try and become queen."

PATTON OCEAN ALLIANCE PATRICK KENNEDY/UNIVERSITY OF BRISTOL, EPA, RAPID

GOING UNDERGROUND

Conventional methods of tracking, such as GPS, rely on radio waves to transmit signals. This works well above the ground but as radio waves are absorbed by soil and moisture they cannot be used to monitor animals that live in burrows.

A team from Oxford University's Wildlife Conservation Research Unit has created a magneto-inductive (MI) tracking system that takes advantage of low frequency magnetic fields' ability to travel through dense materials such as soil. They positioned an array of transmitting magnetic coils above a badgers' sett in Oxfordshire and fitted the animals with lightweight magnetic tracking collars.

The system was able to pinpoint the badgers' positions in three dimensions to a resolution of 30cm. Also, by monitoring the badgers' movements over three months they were able to piece together an accurate 3D map of the sett's structure.





Rare hellbender salamanders once stalked the waters of North America in great numbers – so where have they all gone?

SOMETHING IN THE WATER

The fantastically named 'hellbender' is a giant salamander found in North America. Once abundant, it is now estimated that only 1,100 survive in the wild. With so few animals left, tracking them down can be particularly difficult. Now, a team from the Smithsonian Institute is using DNA-gathering techniques to keep tabs on them. The method, dubbed Environmental DNA (eDNA) monitoring, is so sensitive that it can identify specific molecular markers belonging to the animals in as little as one cup of river water.

The team hopes it will help them identify causes for the salamanders' dramatic decline and then develop a conservation plan. With the hellbender facing a predicted 96 per cent chance of extinction in the next 75 years, eDNA could be a vital tool to help save a creature that has been around since the time of the dinosaurs.

TITANIC MIGRATION

With numbers falling a staggering 96 per cent since 1970, turtledoves are the UK's fastest declining migratory bird species. The race is on to identify the causes of this decline so that conservation efforts can be put in place to potentially save the birds from extinction.

Satellite tracking technology being trialled by the RSPB may provide the answer. While regular tags need to be recovered before the data they record can be downloaded, satellite tags allow researchers to follow the birds' migrations in real time.

In 2014, the RSPB fitted a tag weighing just 4.7g to a turtledove they named Titan, allowing them to track the bird on its 5,600km migration route from Suffolk to Mali. "We know there are issues on their breeding grounds here in the UK but we suspect there are also problems on their migration route, as large numbers from Europe and West Africa are hunted in the Mediterranean," explains the RSPB's principal research manager Guy Anderson.



Satellite trackers could reveal why turtledove numbers are declining

SWEET SAT-NAV

When it comes to finding their way around, bees are up there with the best of them. To put the insects' skills to the test, researchers at Queen Mary University devised a study based on the Travelling Salesman Problem, a mathematical puzzle concerned with finding the shortest possible route around a number of different destinations.

They set up a series of feeding stations around a hive, then used a radar and transponder system to track the bees' movements.

"We set up two radar dishes: one that emits a signal and a second that collects it. A tiny transponder on the back of the bee bounces that signal back at a different frequency so that we can locate its position," explains study lead Lars Chittka.

Once the bees had snacked on all of the food sources, they gradually began to develop faster routes between them. After a few dozen trips, they found the optimal route without fail.



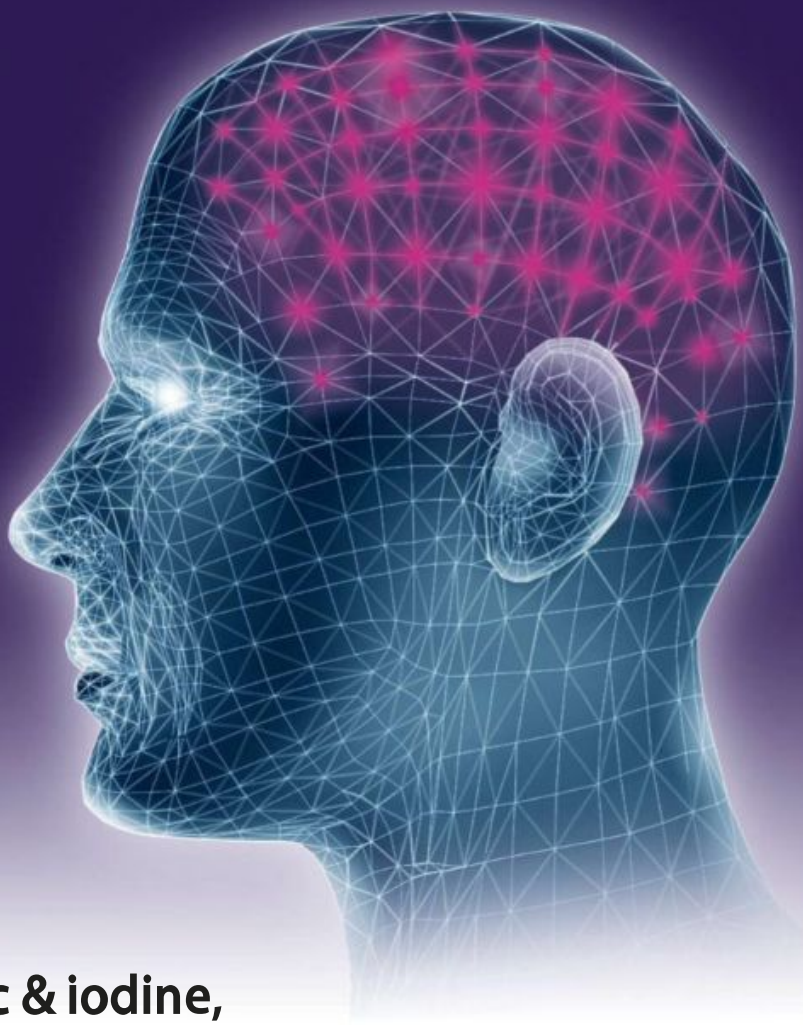
The radio and transponder setup is lighter than a traditional radio transmitter system

Matt Swaine is a freelance writer who previously edited *BBC Wildlife* magazine.

DISCOVER MORE

Visit the BBC iWonder website to find out why the UK is such a migration hotspot for wildlife at **bbc.in/1l8i8mw**

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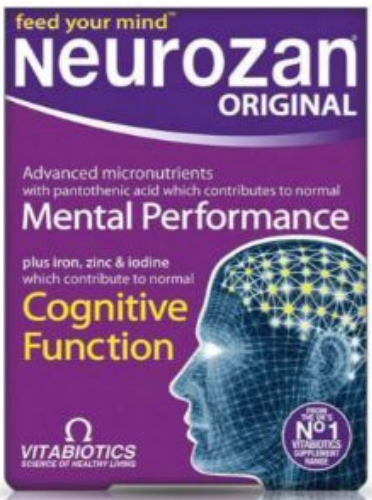
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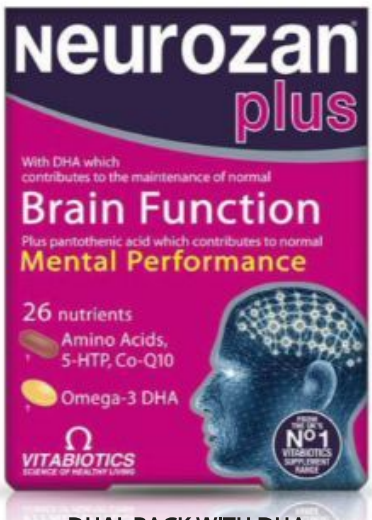
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VITABIOTICS
SCIENCE OF HEALTHY LIVING

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ROBIN INCE ON... MONKEY SELFIES

"THE MONKEY'S SELFIES REVEALED A LEER THAT WOULD FREEZE THE BLOOD OF ANY TINDER USER"



According to artist and lecturer Liz Rideal, "The self-portrait is the artist's most personal form of expression. It is the ultimate means of self-analysis…a bid for eternity." But how true is that when the artist is a monkey?

The camera phone has led to a sharp rise in gregarious narcissism. Social media teeters under the weight of self-obsession and pouting. Some see this as signalling the end times and, worryingly, it appears to have leapt the species divide. Earlier this year, a court dealt with a Celebes crested macaque called Naruto and her right to be the copyright holder and beneficiary of her selfies.

The monkey's selfies revealed a wide-eyed leer that would freeze the blood of any Tinder user. She took her photos in 2011 when the photographer David Slater left his camera lying around. The animal rights group PETA felt that this was a reworking of *The Phantom Of The Opera*, where the true artist was left in the lurch while Slater made money from her work.

The judge ruled in favour of Slater. So was this a defeat for the burgeoning monkey art community?

Non-human art is not new. Desmond Morris, the surrealist painter and zoologist, worked with a chimpanzee called Congo in the 1950s. Congo's canvases can fetch around £4,000. Morris believed that he observed control in Congo's artistic forays: "It wasn't just splish splash".

Elephants, too, have been seen to paint flowers, trees and possibly self-portraits, though not to the standard that would put the great wildlife painter David Shepherd to shame. On a trip to Thailand, Morris and eminent scientist Richard Dawkins took a closer look at these pachyderm Picassos. It would seem that elephants are not inspired by an energetic muse as much as tugged around by a trainer. The elephants seemed to be trained and coaxed into creating their images, and each individual painted the same image over and over again.

Perhaps the best we may hope for is a safari version of Andy Warhol's Factory, eventually creating screenprint after screenprint of Babar or Snorky.

Whether the art is a failure or a sham, we still find a burgeoning body of evidence that more species than we thought have some awareness of their own image. Does this give us any further hints of where this possible introspection may lead in terms of their art?

In 2014, experiments set up by Neng Gong, director of the Institute of Neuroscience at the Chinese Academy of Sciences, managed to teach rhesus monkeys to recognise themselves in a mirror – a behaviour that hadn't previously been seen in these animals. Once the monkeys knew who was in the mirror, their next mission was to concentrate on looking at their own genitals. Here's another reason not to encourage the monkey selfie: the primates will stop embarrassing you when you're at the zoo with your five-year-old, and just sit back and send the genital pics straight to your Facebook account.

Like hoping that a 'counting' horse may eventually hoof its way to a new breakthrough in algebraic equations, the hope of any other animals leading us to the next great art revolution is slim.

Robin Ince is a comedian and writer who presents, with Prof Brian Cox, the BBC Radio 4 series *The Infinite Monkey Cage*.

NEXT ISSUE: LAUGHTER

MAIN ILLUSTRATION: JAMIE COE PORTRAIT: KATE COPELAND



Artist's visualisation of a storm on the surface of Jupiter

ILLUSTRATION: ALAMY



SPECIAL REPORT

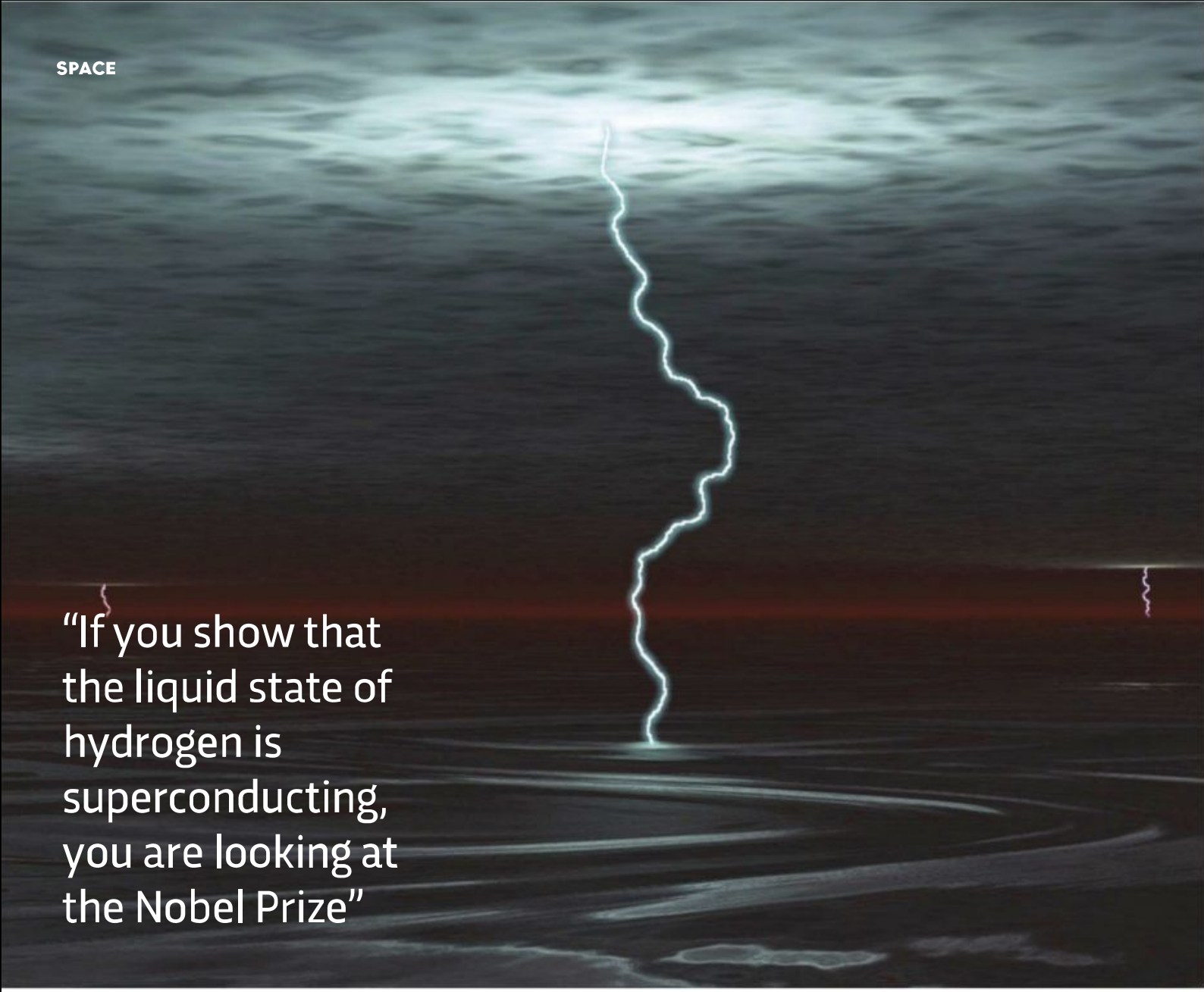
BUILDING A PLANET ON EARTH

In labs around the world, scientists are finding ways to recreate the ferocious conditions inside gas giant planets to finally uncover what lies within

Words: **Andy Ridgway**

Barely audible above the general drone of a lab, there's a high-pitched snap; a nauseating crack. Yet to the physicists at work, this is an all too familiar sound. They are using a device that would fit in the palm of your hand called a 'diamond anvil cell', which could help answer questions about the formation of planets. That tiny snapping sound, roughly the same volume as a coin hitting the ground, tells researchers when they have pushed their equipment beyond its limits.

In January this year, physicists at the University of Edinburgh announced that they had managed to recreate the 'metallic phase' of hydrogen by using diamond anvil cells to squeeze the gas to pressures equivalent to nearly four million times the Earth's atmospheric pressure. This is important because the metallic phase of hydrogen was first predicted to exist 80 years ago, and is thought to play a vital role in the inner workings of a gas giant. Teams from ▶



"If you show that the liquid state of hydrogen is superconducting, you are looking at the Nobel Prize"

ABOVE: Hydrogen seas swirl beneath a turbulent sky in this artist's impression of Jupiter's surface

around the world have been clamouring to create it for decades.

STRANGE STUFF

Gas giants do not have a solid surface and are mainly made up of hydrogen and, to a lesser degree, helium (see 'Anatomy of a gas giant', right). On Earth, we think of hydrogen as a colourless gas. But when it is subjected to the intense pressures present inside gas giants, it becomes a fluid. And at even higher pressures, near the planet's core, this fluid becomes 'metallic' and is able to conduct electricity. Or that's what's thought to happen.

"Our field is extremely contentious," says Prof Eugene Gregoryanz at the University of Edinburgh, whose team became the first to create hydrogen's metallic form earlier this year. "There have been many, many claims of having produced the metallic form before." But, he says, these claims were later disproved. It means that he's now being cautious about his achievement.

"Although we do think that this phase of hydrogen we have reached is conducting, we don't have a bulletproof case. So we are saying this is the precursor to the metallic phase," says Gregoryanz. It's not only the fact that hydrogen makes up the bulk of gas giants that makes its metallic phase such a focal point for research. "It's also because of the utterly bizarre and unseen anywhere properties hydrogen is theorised to have at high pressure," he adds. Among which, is that the fluid form of hydrogen is superconducting – capable of conducting electricity with zero resistance. "I'm pretty sure that if you show that the liquid state of hydrogen is superconducting or superfluid, you are looking at the Nobel Prize in physics," he says.

The diamond anvil cell is an incredibly straightforward scientific tool, consisting of a

PHOTO: SCIENCE PHOTO LIBRARY

metal frame that can be screwed tighter and tighter together, often with wrenches. Inside the frame sit two flawless diamonds, worth a few hundred pounds each, that are drawn together as the device is tightened. Hydrogen trapped between these diamonds is crushed at increasing pressures as the screws are tightened.

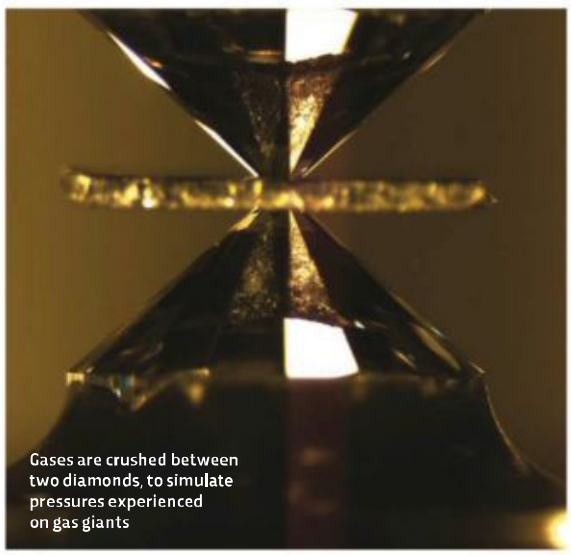
Diamond is one of the hardest natural substances known, yet it often breaks at the high pressures created in anvil cells. That's especially true when it's hydrogen being squeezed – it becomes reactive at high pressures, weakening the diamond. "If you work with diamond anvil cells, you hear diamonds breaking a lot and it's not your favourite sound," says Dr Stewart McWilliams, who is using these devices at the University of Edinburgh. Progress has been made over the years by refining the technique so the diamond holds out at higher pressures.

FOGGY VIEW

Researchers define success in this field as buying themselves a fleeting moment long enough to get usable results before their equipment breaks. "It's down to the nanosecond," says McWilliams. "But you can start to see interesting things happening before the whole system breaks apart."

Aside from the short period of time in which to gather data, the other major challenge is that at the intense pressures required, many of the analytical techniques you might want to use – such as X-ray diffraction that would show whether the hydrogen has turned into a fluid – simply won't work. It means that while researchers are creating a window into gas giants, it's a decidedly hazy one.

Then there's the question of the pressures diamond anvil cells can create. While the four



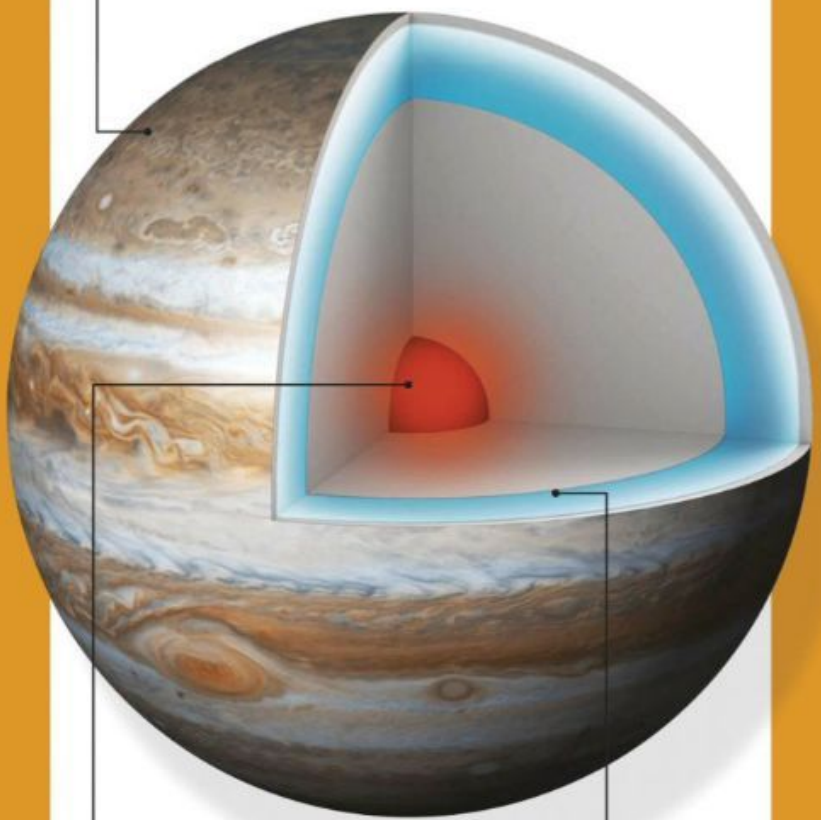
Gases are crushed between two diamonds, to simulate pressures experienced on gas giants

PHOTOS: SCIENCE PHOTO LIBRARY, STEVE JACOBSEN

ANATOMY OF A GAS GIANT

The largest planet in the Solar System still hasn't given up all its secrets

It's the outermost layer of Jupiter we're most familiar with, thanks to photos taken with telescopes. Here there are layers of visible clouds of ammonia and water. But all is far from clear. For instance, astronomers have been struggling to explain the orange and brown colour of Jupiter's outer layer. One explanation is that it's down to trace elements, such as sulphur.



The hydrogen, which makes up the bulk of a gas giant (90 per cent in the case of Jupiter) transforms from the colourless gas we're familiar with on Earth, to a fluid. At even greater depths, this fluid starts to conduct, just like a metal. Right at the heart of a gas giant is a core thought to be made up of water, methane and nitrogen. Exactly where these transitions take place and the properties of these components under extreme gas giant conditions is the stuff of current research.

In some ways, a gas giant like Jupiter is more like a star than a planet. It has no solid surface – it's simply a ball of hydrogen, helium and a dash of other elements. Venture deeper into the planet, and things start to turn decidedly strange.

"If you work with diamond anvil cells, you hear diamonds breaking a lot and it's not your favourite sound"



The OMEGA laser at the Laboratory for Laser Energetics crushes gas giant gases



million atmospheres generated by diamond anvil cells take us deeper inside a gas giant than we've ventured before, it is far removed from the pressures near the core of Jupiter, which can reach up to 4,500 million times Earth's atmospheric pressure. But there *is* a way to get closer to these unimaginable pressures here on Earth.

Instead of using blocks of metal tightened with wrenches, Dr Jon Eggert at the Lawrence Livermore National Laboratory in California is using lasers that create high-pressure shockwaves. At facilities usually used for nuclear fusion experiments, such as the OMEGA laser at the Laboratory for Laser Energetics (LLE) in New York, beams of lasers are focused on tiny containers filled with gas giant gases. When these containers are turned into a plasma, the resulting shockwave crushes the gas within.

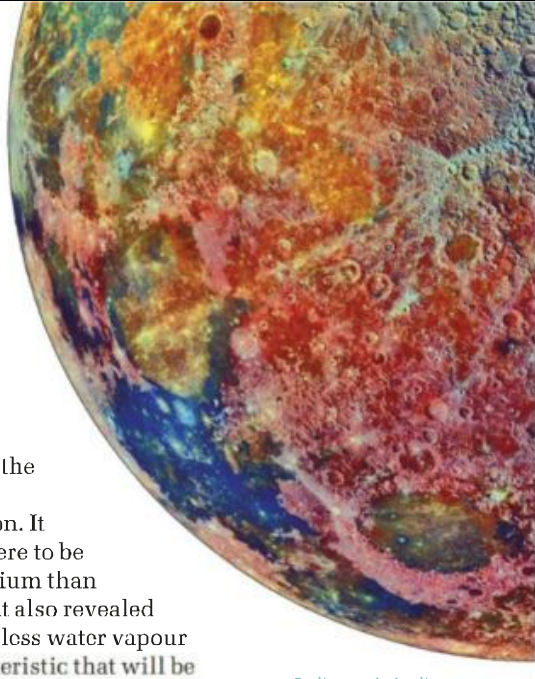
SHOCKWAVE SCIENCE

While much higher pressures are achievable in these 'dynamic experiments', high temperatures are also created. "You can measure temperatures in shocks up to 100,000°C and the temperature in the interior of Jupiter is estimated to be in the order of 10,000°C to 20,000°C," says Eggert.

Gregoryanz points out another problem, saying that while the pressures created using the shockwaves are "absolutely surreal", getting usable data is even more of a challenge than with diamond anvil cells. "They can create these pressures but they can't really measure anything yet," he explains. "Even the measurement of pressure is a little bit contentious."

JOURNEY INTO THE UNKNOWN

When Juno reaches Jupiter later this year, it will carry on the vital work started by Galileo



On its way to Jupiter, Galileo also paid a visit to our Moon

PHOTOS: NASA X2, LLNL

There were many questions about the inner workings of Jupiter until the Galileo spacecraft paid it a visit. Launched aboard the Space Shuttle Atlantis in 1989, this 2.5 tonne lump of finely tuned instruments took six years to reach the Solar System's largest planet.

On the day Galileo arrived, a probe was flung into Jupiter's dense atmosphere. During the first two minutes of descent, the air temperature was twice as hot as the Sun's surface. Despite such brutal conditions, the probe's instruments provided tantalising information about this planetary behemoth.

As well as detecting lightning bolts more powerful than those on Earth, the probe provided intriguing data about the planet's composition. It showed there to be far less helium than expected. It also revealed there to be less water vapour – a characteristic that will be investigated further when Juno reaches Jupiter in July.



Juno, seen here being assembled, was launched in August 2011 and will reach Jupiter later this year

Despite the challenges, Eggert says he has been making progress using shockwaves. In yet to be published research conducted at the LLE, he and his colleagues have been investigating what happens to mixtures of hydrogen and helium at high pressures. By pre-compressing the mixture using a diamond anvil cell, they were able to keep a lid on the temperature after the shockwave.

The experiments show that because of the temperature and pressure distributions in Saturn, these gases are much more likely to stop mixing and 'phase separate' at high pressure than in the conditions found in Jupiter. So inside Saturn, much of the hydrogen and helium will have separated. "The extra energy of the helium falling into the centre of the planet might be what's heating it," says Eggert. If helium *is* falling and creating heat by friction, it would answer one of the biggest mysteries of Saturn – why it emits 80 per cent more energy than it absorbs from sunlight given that there should be no residual heat after its formation.

IMMINENT ARRIVAL

But we don't just have experiments here on Earth that can tell us about the inner workings of gas giants. In 1995, NASA sent a probe from the Galileo spacecraft into Jupiter's atmosphere. Before disintegrating under the intense pressure and heat, it made some intriguing discoveries, including that there was much less water vapour than expected (see 'Journey into the unknown', above). Finding out why this is the case is one of the main targets of NASA's Juno spacecraft, which will reach Jupiter in July and start building a more detailed picture.

Juno's microwave instrument will try to determine whether there is water lurking inside Jupiter's core. It would provide evidence for the leading theory of how gas giants like Jupiter form; a core of ice developing that gets so large it draws in hydrogen. But it's not just where the water is hiding that will provide us with clues about how gas giants develop. Understanding how hydrogen behaves now, and where it changes between its different phases within a gas giant as the pressure ramps up with increasing depth, will also allow us to work backwards to the birth of these planets.

All this could not have come at a better time. The huge planets first spotted by Kepler are much closer to their stars than the prevailing models of solar system formation would predict. So a better knowledge of planetary formation will come in handy as we realign our models to our new knowledge of other solar systems.

It's perhaps no surprise then, with so many big questions to be answered, that physicists around the world are prepared to endure the sound of a few cracking diamonds.

Andy Ridgway is a senior lecturer in science communication at the University of the West of England.

DISCOVER MORE

Watch and listen to clips about the Galileo mission to Jupiter at **bbc.in/1RFDadc**

Stay abreast of all the latest space news by tuning in to *The Sky At Night*. Catch up on iPlayer at **bbc.in/1F1NHWR**

MORE THAN A LOAD OF HOT AIR?

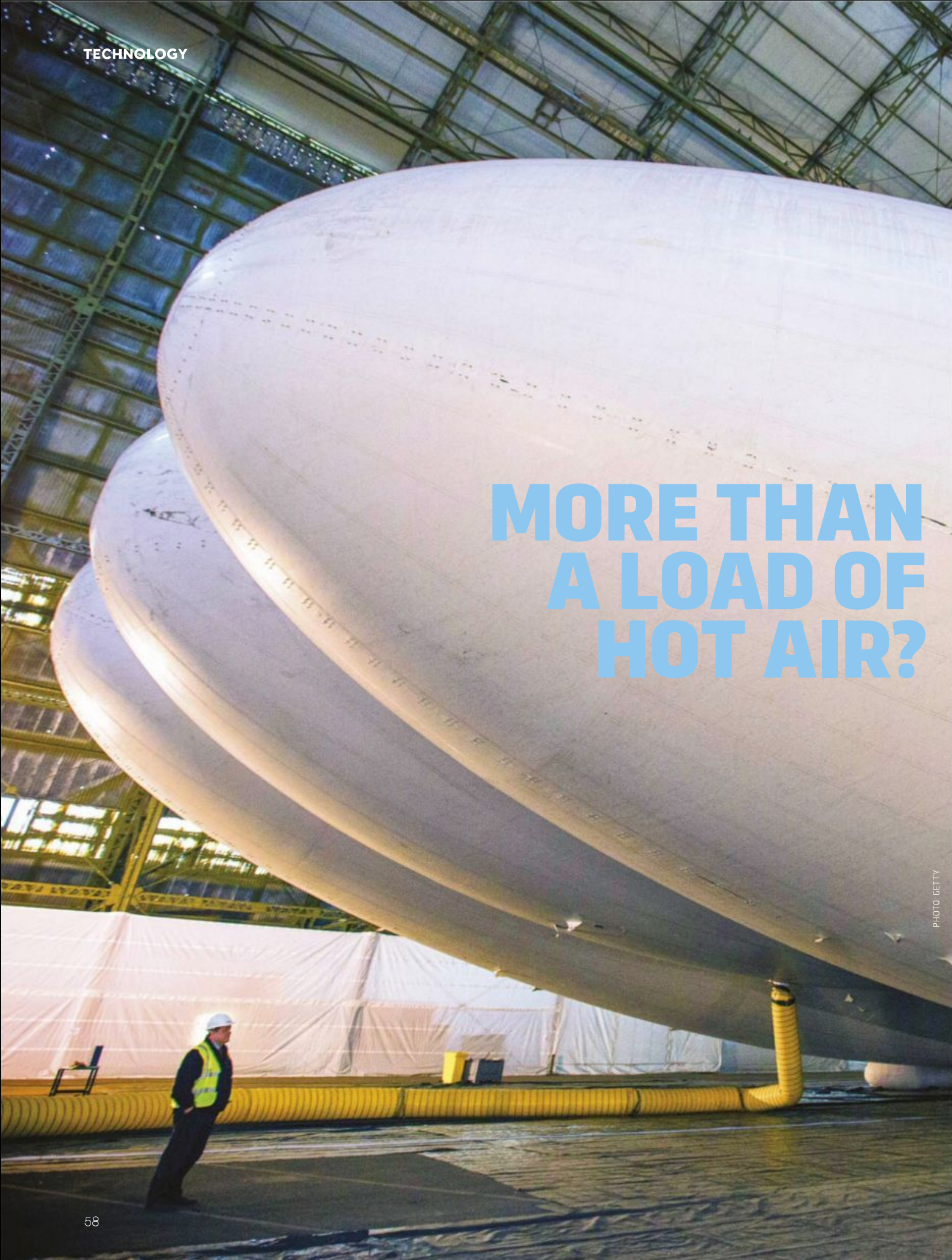


PHOTO GETTY

Airships are one invention that seem to be consigned to the history books. But this year they could be making their way back to our skies

Words: **Neil Ashton**



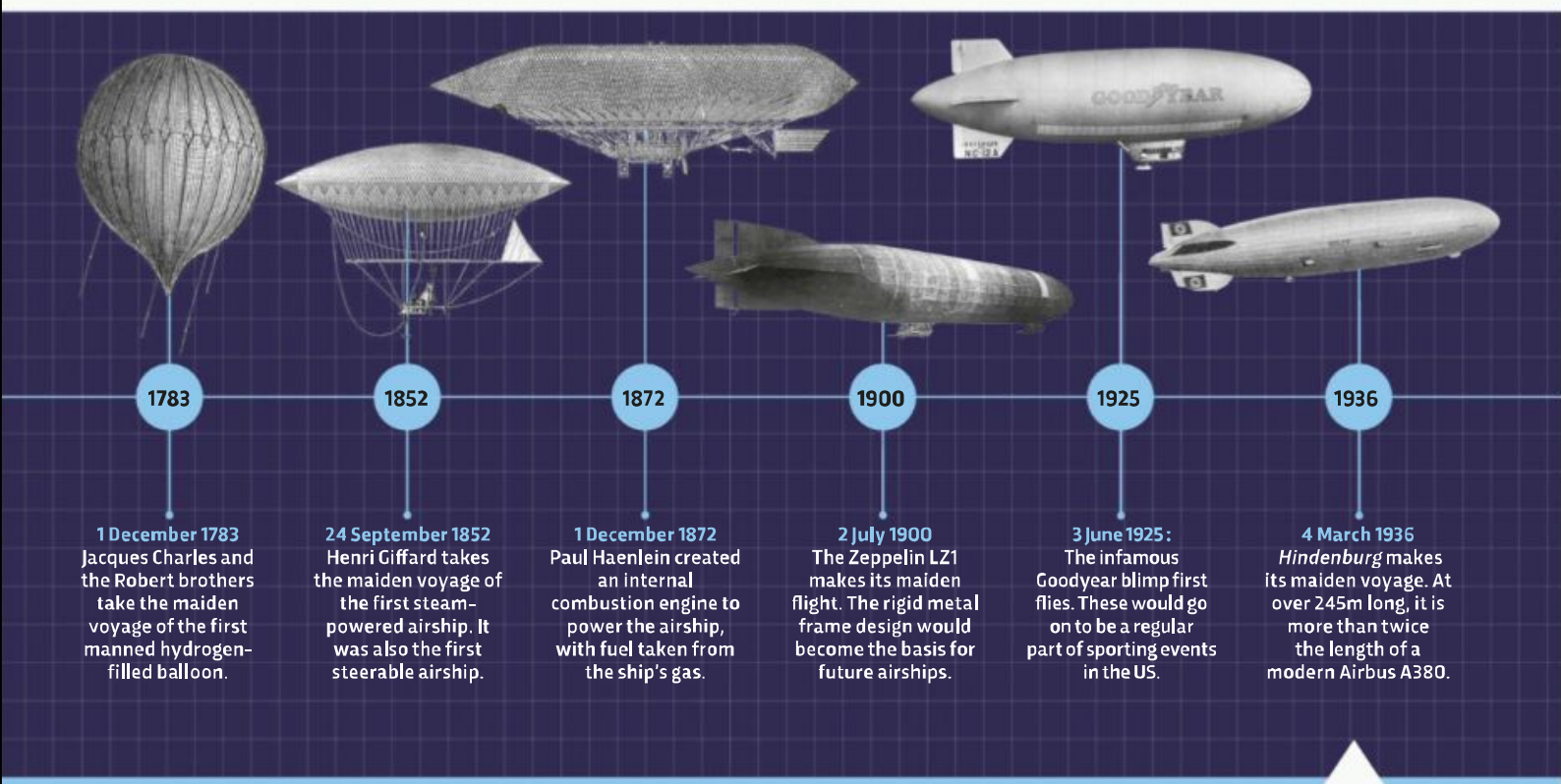
What's bigger than a football pitch, can withstand bullets, and has been designed in the UK? The Airlander, that's what...

On 6 May 1937, people around the world watched their TV screens in horror as German airship the *Hindenburg* violently burst into flames while attempting to dock at a mooring mast in New Jersey. Seconds after igniting, the 245m-long craft was shown nose-diving into the ground before crumbling into a pile of ash. The accident claimed 36 lives and shattered the public's confidence in the safety of airships.

Yet it is largely forgotten that in the months prior to the accident, the *Hindenburg* spent a short-lived golden age ferrying passengers across the Atlantic in comfort. Now, 80 years on from its maiden flight, could we see airships returning to our skies?

UP, UP AND AWAY

Airships rely on the Archimedes principle to get them off the ground. The difference between the density of the gas inside the airship and the air outside creates an upward force that propels them into the air. It is exactly the same effect seen in children's party balloons. Early airships such as the *Hindenburg* were filled with hydrogen, as it is the lightest gas and therefore offers the maximum possible lift. The downside being that it is also extremely flammable. This meant that airships



1783
1 December 1783
Jacques Charles and the Robert brothers take the maiden voyage of the first manned hydrogen-filled balloon.

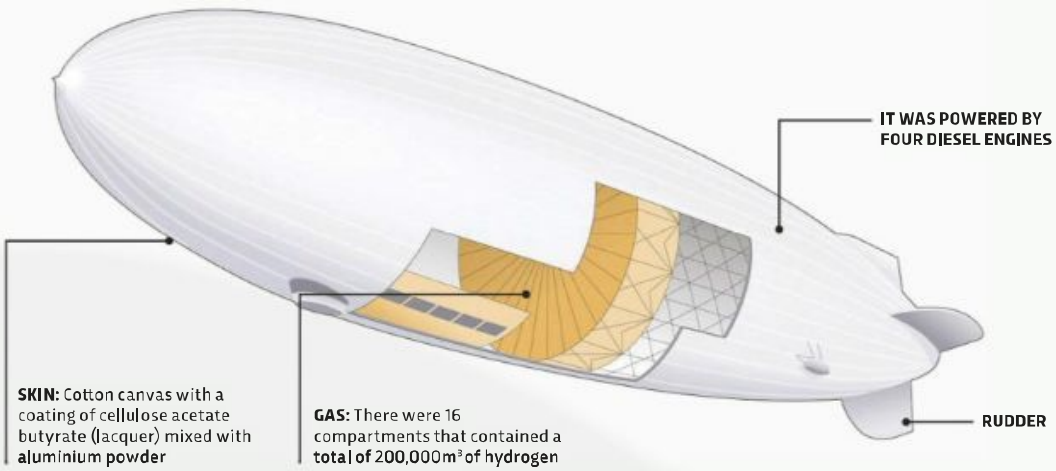
1852
24 September 1852
Henri Giffard takes the maiden voyage of the first steam-powered airship. It was also the first steerable airship.

1872
1 December 1872
Paul Haenlein created an internal combustion engine to power the airship, with fuel taken from the ship's gas.

1900
2 July 1900
The Zeppelin LZ1 makes its maiden flight. The rigid metal frame design would become the basis for future airships.

1925
3 June 1925:
The infamous Goodyear blimp first flies. These would go on to be a regular part of sporting events in the US.

1936
4 March 1936
Hindenburg makes its maiden voyage. At over 245m long, it is more than twice the length of a modern Airbus A380.



HINDENBURG

PROVIDED A REGULAR SERVICE BETWEEN EUROPE AND THE US

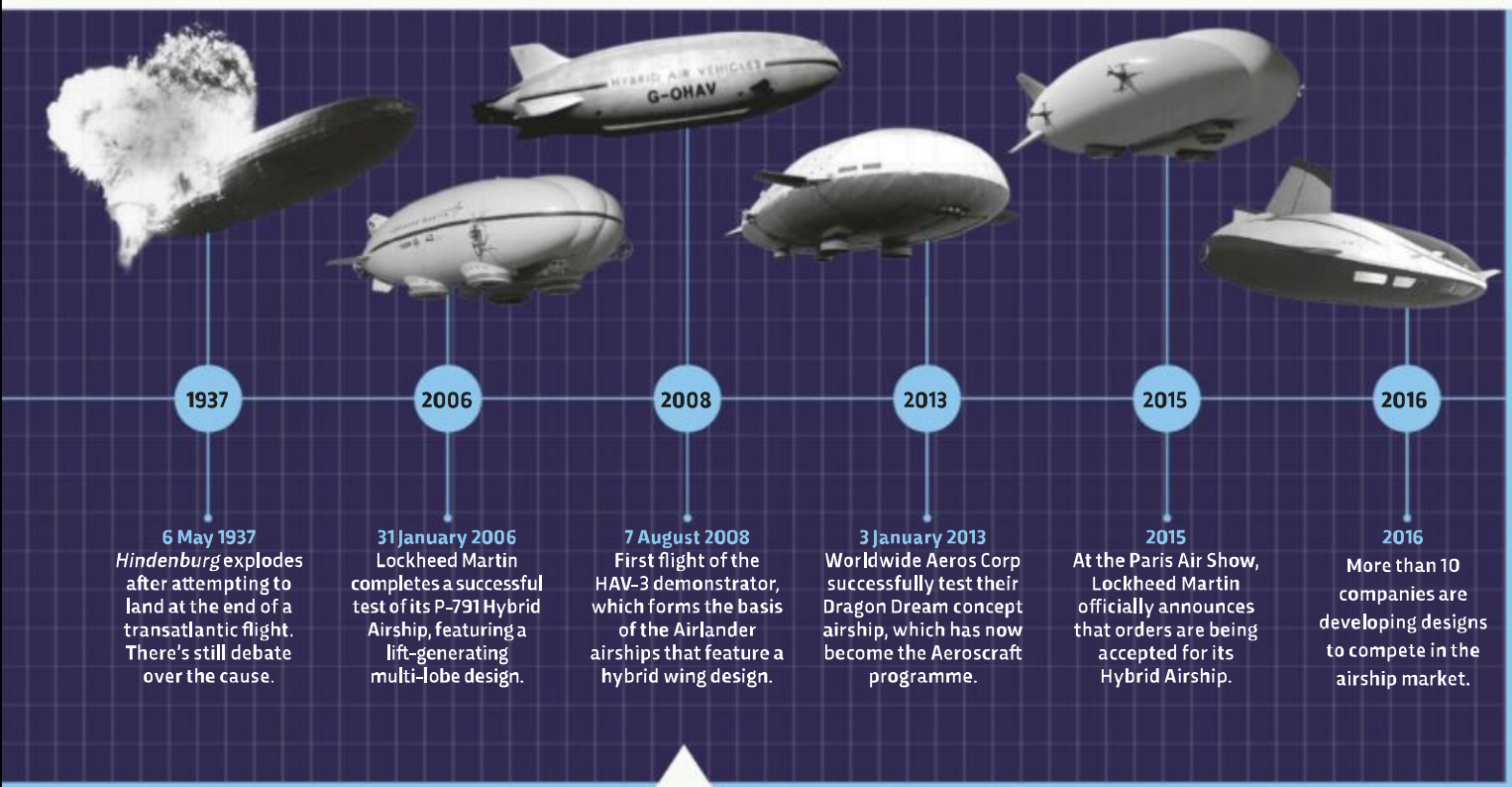
The *Hindenburg* was a luxurious aircraft that offered fast passage across the Atlantic. The engineers originally wanted to use helium to provide lift, but couldn't secure import of the gas from the US.

PHOTOS: GETTY X5, CORBIS, CAN STOCK. ILLUSTRATION: ACUTE GRAPHICS

"Airships can offer a cheap and flexible way to ship cargo to remote locations"

were vulnerable to explosions caused by fuel leaks and lightning strikes, especially as they tended to fly below the clouds. The *Hindenburg* disaster is, of course, a sobering example of the dangers of using hydrogen. These days, airships are filled with helium. This gas is slightly heavier than hydrogen, so provides less lifting force – but crucially it isn't flammable.

In contrast to the *Hindenburg*, most recently designed airships are not trying to compete with well-established forms of passenger travel. Instead, airships can offer a cheap and flexible way to ship cargo to remote locations where paved roads and other infrastructure is scarce or even non-existent. Example uses could be delivering equipment and personnel to hard-to-reach mines and drilling sites, or perhaps even to the Arctic Circle, which is fast becoming a key focus of big business thanks to the large



1937
6 May 1937
Hindenburg explodes after attempting to land at the end of a transatlantic flight. There's still debate over the cause.

2006
31 January 2006
Lockheed Martin completes a successful test of its P-791 Hybrid Airship, featuring a lift-generating multi-lobe design.

2008
7 August 2008
First flight of the HAV-3 demonstrator, which forms the basis of the Airlander airships that feature a hybrid wing design.

2013
3 January 2013
Worldwide Aeros Corp successfully test their Dragon Dream concept airship, which has now become the Aeroscraft programme.

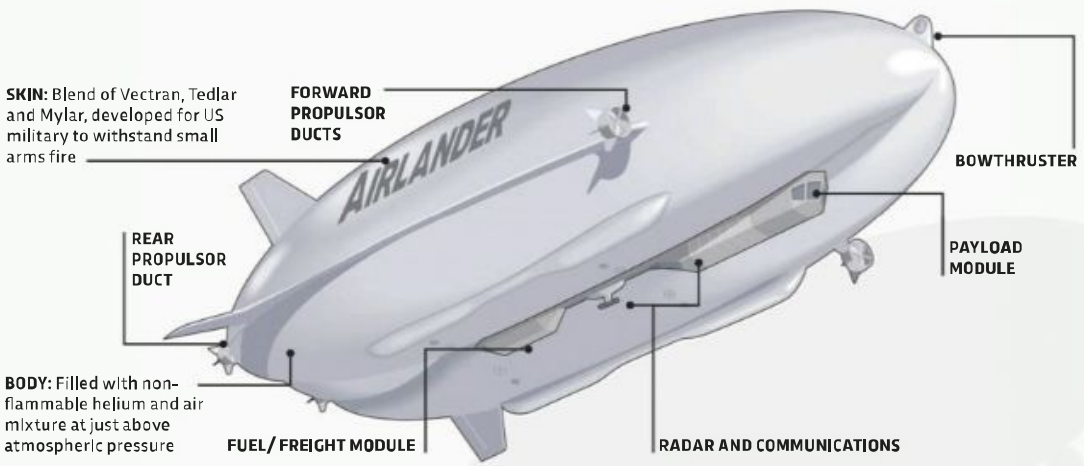
2015
2015
At the Paris Air Show, Lockheed Martin officially announces that orders are being accepted for its Hybrid Airship.

2016
2016
More than 10 companies are developing designs to compete in the airship market.

AIRLANDER

WORLD'S LONGEST AIRCRAFT TO MAKE UK FLIGHT

Originally sold to the U.S. Army, the Airlander Hybrid Air Vehicle – a huge helium airship as large as a football pitch – will be flown for the first time by its UK developers later this year.



PHOTOS: AIRLANDER, AEROS CORP'S X2 ILLUSTRATION: GRAPHIC NEWS

untapped oil reserves hidden underneath the ice.

BEST OF BOTH WORLDS

Over the last few years, a number of companies have been developing new airship designs in the hope of competing for a piece of this emerging market. Lockheed Martin, one of the world's largest aerospace and defence companies, recently unveiled the Hybrid Airship at the Paris Air Show. It combines a traditional helium gas-filled body along with an aerodynamic multi-lobe hull fitted with aeroplane-like wings to provide additional lift. This means it requires a smaller volume of helium than a standard airship. It has a top speed of 111km/h (69mph), a range of 2,600km and burns just one-tenth of the fuel per ton of cargo compared to a helicopter, Lockheed says.

"The first 10 years of what we did was evolving to the multi-lobe structure. It's a careful balance between weight, performance and aerodynamics," explains Bob Boyd, programme manager for the project at Lockheed Martin's Skunk Works. "You can do a single lobe design, or you can have five, seven or 20 lobes. There are a wide variety of combinations, but economically the best combination is what we have."

The hybrid design also provides versatility when it comes to taking off. When loaded with more than 70 per cent of its maximum cargo weight of 21,000kg, the Hybrid Airship can take off in a similar fashion to an aeroplane. To deal with unpaved surfaces, Lockheed engineers have developed an air cushion system that allows the craft to hover slightly above the ground as it takes off.



ABOVE| Lockheed Martin's Hybrid Airship can take off like a conventional airship, or like an aeroplane

BELOW| Airships still have wide-ranging appeal and are often called upon for promotional events and tourism



As the helium gas still provides 70 to 80 per cent of the lift, the airship can take off and land vertically like a conventional airship when carrying less than 70 per cent of its maximum cargo weight. The team hopes that the design will prove both versatile and cost-effective.

"There are only a small number of design metrics that matter, the most important one by far is the cost. We are trying to build a platform that fits the costs and transport needs of different customers," says Boyd. "Our vision is that our aircraft will be flying 24/7, 300 plus days a year, most of the time to the same place."

A BALLAST FROM THE PAST

Early airships all required some form of external ballast when they landed to stop the airship from taking off when passengers and cargo were removed. Typically, this ballast would be water, but having access to external ballast in remote locations can be a problem. Some companies have developed solutions to remove the need for external ballast altogether. One such company is Worldwide Aeros Corp, which is developing the Aeroscraft



Aeroscraft uses a system similar to a submarine to help it take off and land

PHOTOS: GETTY, WORLDWIDE AEROS CORPS



ABOVE AND BELOW: Mines and mountains can be tough to access via road or rail, but the Airlander can navigate to these locations with ease

airship. When the craft is landing, the COSH (Control Of Static Heaviness) system compresses some of the helium gas within the aircraft into tanks, which makes it heavier. It then releases it back into the main structure as it wants to take off. This system is similar to the way in which a submarine controls its depth.

"The ability to hover for hours over a targeted area and rapidly load or offload cargo without ballast problems is what sets Aeroscraft apart from the rest," says engineering manager John Wertz.

The team also took a unique approach to designing the landing gear. Rather than landing on wheels or skids, Aeroscraft uses specially designed landing cushions. This enables it to land safely on almost any surface, including water. Air can also be blown or sucked through the cushions, enabling the airship to operate like a hovercraft when taxiing, or grip the ground during loading and unloading.

FLYING HIGH

A British company, Hybrid Air Vehicles, is also in the final stages of developing a cargo airship, the Airlander 10. Like Lockheed's Hybrid Airship, Airlander is filled with helium and features a multi-lobe, winged hull that provides the craft with around 40 per cent of its lift.



"One of the keys to making Airlander commercially viable is the strong and lightweight hull material. Its layers of Tedlar, Mylar and Vectran reinforced fibres give it the protection, strength and helium-retention features vital to keeping the shape of the hull in all weather and flight conditions," says head of flight sciences David Stewart.

Airlander has a cruising speed of 148km/h, it can carry a maximum load of 10,000kg and is able to stay airborne for up to five days. Each of its four diesel engines can be rotated to point up or down. This gives the craft the ability to hover, as well as land on almost any surface be it ice, sand or water.

Though it seems unlikely that we will be piling into airships heading for exotic destinations anytime soon, these giants of the sky could nevertheless have a second, slightly less glamorous, golden age on the horizon.

Dr Neil Ashton is an aerospace engineer and visiting research fellow at the University of Oxford.

DISCOVER MORE

Listen to the famous clip by US broadcaster Herbert Morrison after the *Hindenburg* burst into flames at **bbc.in/10sLI8g**

PHOTOS: AIRLANDER


PHILIPS
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Turn your everyday lighting into an extraordinary experience.
Play with colors or sync lights with your music, TV and games for an immersive effect. The possibilities are endless once you start exploring.
And with hundreds of apps to choose from, the only real limit is your imagination.
innovation you
Paint with light
Sync lights with music and movies
Light schedules for home automation
Light for your well-being
hue PERSONAL WIRELESS LIGHTING
PHILIPS
hue
White and color ambience
Limitless possibilities
connected to you
Works with Apple HomeKit
PHILIPS



ROBERT MATTHEWS ON... RESEARCH FADS

"RESEARCHERS AREN'T QUEUEING UP TO WORK ON SOMETHING UNFASHIONABLE LIKE THE MENOPAUSE"



Snoods, spacehoppers, hoverboards... fashions come and go. When they're later dusted off and wheeled out, usually by TV documentary makers, they often seem laughable.

Even as a kid in the 1970s, I couldn't understand why anyone would want to buy a pet rock. Still, at least that fad only affected pocket money – unlike the cosmetics marketed in the 1930s, which claimed to make a woman's face glow through the wondrous effects of radioactivity.

Science has helped debunk fads over the years, from silly diets to screens for blocking 'harmful radiation' from PCs. But science itself is also prey to fashion, and the consequences aren't always quite so funny.

When I was a student, researchers working on the properties of materials were seen as second-rate drudges messing about in what was called 'dirt physics'. The proper term is 'materials science', and the theory behind it is known as solid-state physics. Even so, one Nobel Prize-winning particle physicist could not resist referring to it as 'squalid state'.

All very droll, except that such attitudes did little to boost recruitment into the field. Which is a shame, as 'squalid-state physics' is now at the centre of a technological revolution. Understanding how electrons and photons behave in materials holds the key to highly efficient solar cells, long-life batteries and a host of other game-changing technology.

What's more, refusing to follow scientific fashion can bring huge rewards as one materials scientist showed in the 1980s. Shuji Nakamura was fascinated by a typically boring squalid-state challenge: getting high-frequency light out of semiconductors.

As a loner in an obscure Japanese company, Nakamura knew he had little chance of success if he followed the fashionable ideas pursued by everyone else. So he focused on ideas everyone 'knew' were hopeless. It worked. He won the Nobel Prize in 2014 and opened the way to the biggest breakthrough in light technology since Thomas Edison: bright white LEDs.

One area in which fashion seems especially influential is medicine. Fields like cardiac surgery and neurology are proverbially glamorous, not least because of the complexity of what they do. Recently, gene therapy, stem cell research and cancer immunology have garnered global publicity and funding to match, which is understandable given their huge promise.

But what about all those less glamorous areas of research, and the scientists toiling away with little publicity and less funding? Who cares – surely they're less glamorous because they're not as important?

Not so. Take the research, or lack of it, into a boring, unglamorous condition that affects over a billion people worldwide: chronic pain. We all know people struggling along with painful conditions like arthritis and spinal damage. Yet despite their prevalence, medical science can offer little but temporary respite.

Or how about a condition affecting half the global population when they reach middle age: the menopause. Hundreds of millions of women suffer its effects, from disturbed sleep and mood swings to reduced cognitive abilities. But the remedies on offer are either unproven, temporary or risky. And young researchers aren't exactly queueing up to work on so unfashionable a problem.

In the end, it hardly matters what ideas are in or out of fashion in, say, particle physics. But it certainly does matter in medical science, and the real 'fashion victims' could be us.

Robert Matthews is visiting professor in science at Aston University, Birmingham.

DISCOVER MORE

Listen to a *5 Live News Specials* episode about the menopause and HRT at **bbc.in/1cMOXWM**

NEXT ISSUE: DIET SCIENCE

MAIN ILLUSTRATION: ADAM GALE PORTRAIT: KATE COPELAND

YOUR FUTURE SMART HOME

Bricks that heal, paint that never stains and air conditioned beds, let us show you around the home of the tomorrow you could build today...

Words: Luke Edwards Illustration: Daniel Bright



OUTSIDE

ENERGY

Renewable energy sources are what the future is all about. They help homes become self-reliant and go off-grid. That's great if you're expecting the zombie apocalypse, but renewable energy is also practical, saves money, helps the environment and increases the value of a property. Some energy suppliers even pay you to pump juice back into the grid.

The Smartflower POP is one of the most attractive and efficient examples of solar panels yet. Smartflower POP will 'bloom' open in the morning and close up at night. So it's space-efficient, too. Best of all, you can take it with you when you move!

WALLS

Self-healing is no longer reserved for video game characters: buildings can do it too. Scientists have created a coating that contains microcapsules. When a coated concrete surface becomes damaged, the capsules break open and release a solution, which fills the crack and turns into a water-resistant solid when exposed to sunlight.

PAINT

Self-cleaning paint is one development aimed at keeping houses looking new. One company, StoLotusan, has developed a paint that won't let water adhere to it. Slap it on your property, then when it rains, any dirt will be lifted from the surfaces of the walls and washed away. Plus, as the paint doesn't get damp, microorganisms such as algae, fungi and bacteria can't survive, so it's cleaner and more hygienic than most normal walls. The fact it's available in 500 colours is just a bonus.

SECURITY

Mark Zuckerberg, creator of Facebook, has announced he'll be spending this year creating his own version of Iron Man's artificially intelligent butler, Jarvis. Zuckerberg wants the butler to detect faces when people ring the doorbell, to determine whether or not to open the door. So if you're busy and a Facebook friend shows up it can determine whether or not to open the door. Here's hoping there aren't too many evil doppelgangers out there...

If you don't fancy giving Facebook access to your home, then there's August, a smartphone-controlled lock that lets you share virtual 'keys' to your friends' and family's phone numbers.

LAWNMOWER

A lawn takes a lot of time and effort to maintain... unless you employ the services of a robot lawnmower! Thanks to laser markers, the Husqvarna Automower 305 can sense boundaries in your garden, it recharges itself and it'll never bring muddy boots in the house. Better yet – you could preorder an EcoMow, a robomower that turns the grass it cuts into biofuel pellets, which it can use as fuel.

THE MOWER

1986
Remember mixing together diesel and oil for two-stroke? Or pushing a heavy, noisy and smelly mower about?

2016
Autonomous mowers can charge themselves and stay within boundaries to keep the plants safe.

2036
Genetically modified grass that grows to a uniform length could eliminate the need for mowing.





LG's flexible screen can be rolled up and popped in a cupboard until needed

LIVING ROOM

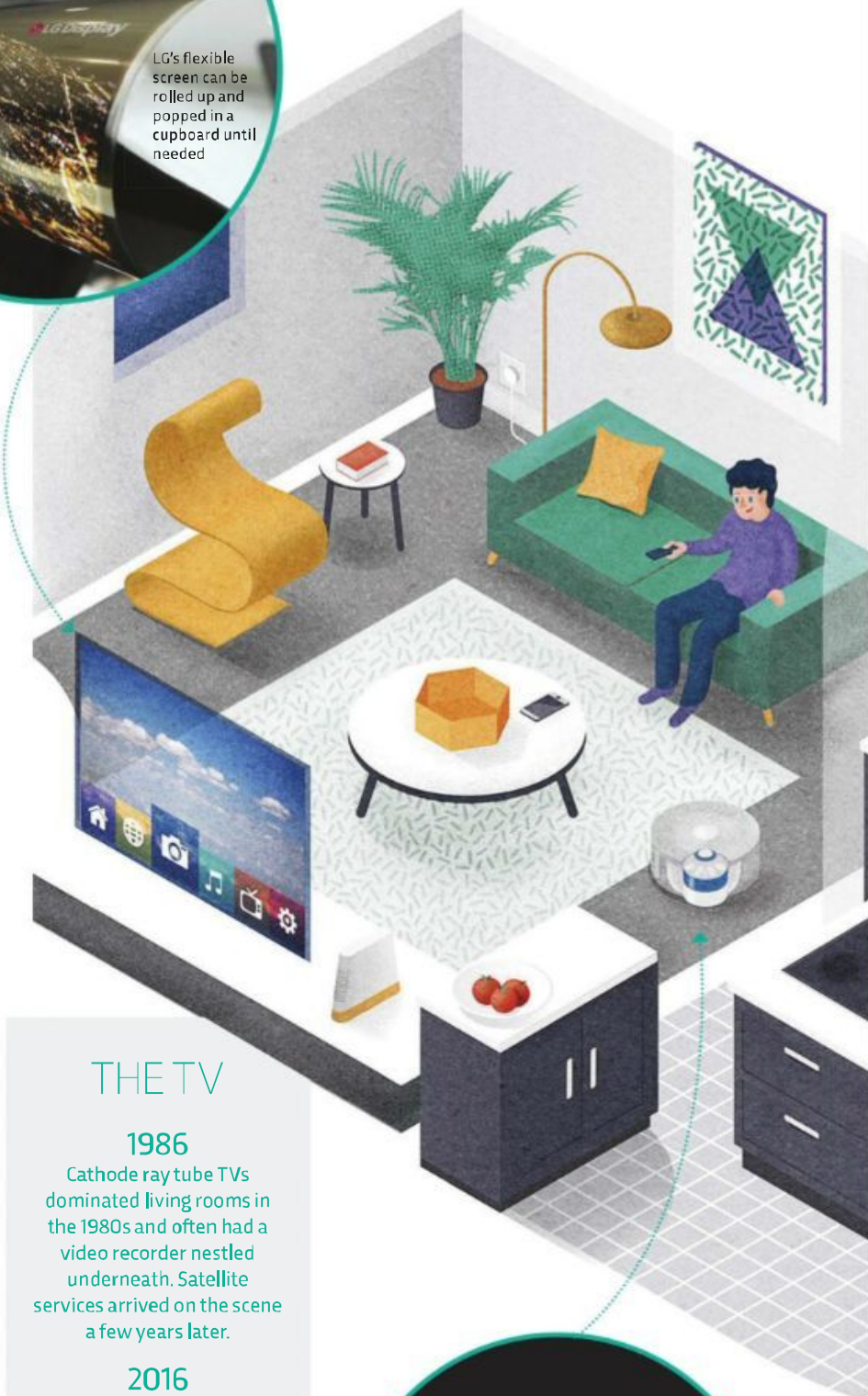
TELEVISION
LG has now introduced OLED screens that can be rolled up like a newspaper. Panasonic, on the other hand, has released a prototype of a television screen that's transparent when not in use. Soon we could see improved integration into our living rooms, where our television screens double up as windows or walls.

LIGHTING
Why just switch the lights on when you could create an immersive mood instead? Philips Hue is a wireless lighting system that lets you control light colour and intensity from a smartphone app, but Mipow's Playbulb goes one better. As well as being a pretty nifty light bulb, it's also a wireless speaker. When you're putting the kids to bed, use it as a nightlight and get it to play their favourite lullaby. More of a party animal? Set it to pulse in technicolour. A minimalist's dream.

CLEANING
While Hoover may have once been synonymous with vacuum cleaners, Dyson is fast becoming the staple for the task. The company has come to the autonomous robot vacuum market late, because it wanted to get it perfect. The Dyson 360 Eye uses "complex mathematics, probability theory, geometry and trigonometry to map and navigate a room," says the company. The 360 Eye will self-charge, too. The next step? One that will empty itself so human hands never need touch the smart robo-servant at all.

PRINTING
3D printing is still a fairly specialist hobby, but soon we'll see an advanced printer in every home. Imagine raw materials being piped to your home, and a room-sized printer where nearly anything you can image can be printed. For now, fans of 3D printing can use sites like Thingiverse and Shapeways to create custom furnishings, but in the future, their repertoire could expand to include many more materials.

WI-FI
Wi-Fi is everywhere, and so is Bluetooth. Wi-Fi once operated at frequencies of 2.5GHz, but now works at 5GHz for a slightly shorter range but higher bandwidth. Now it's gone the other way with HaLow, a low-power, long-range Wi-Fi. This is a bit like Bluetooth and will allow devices such as sensors and wearables to talk to each other without guzzling power. The result should be easily installable smart home upgrades with less reliance on mains power connections.



THE TV

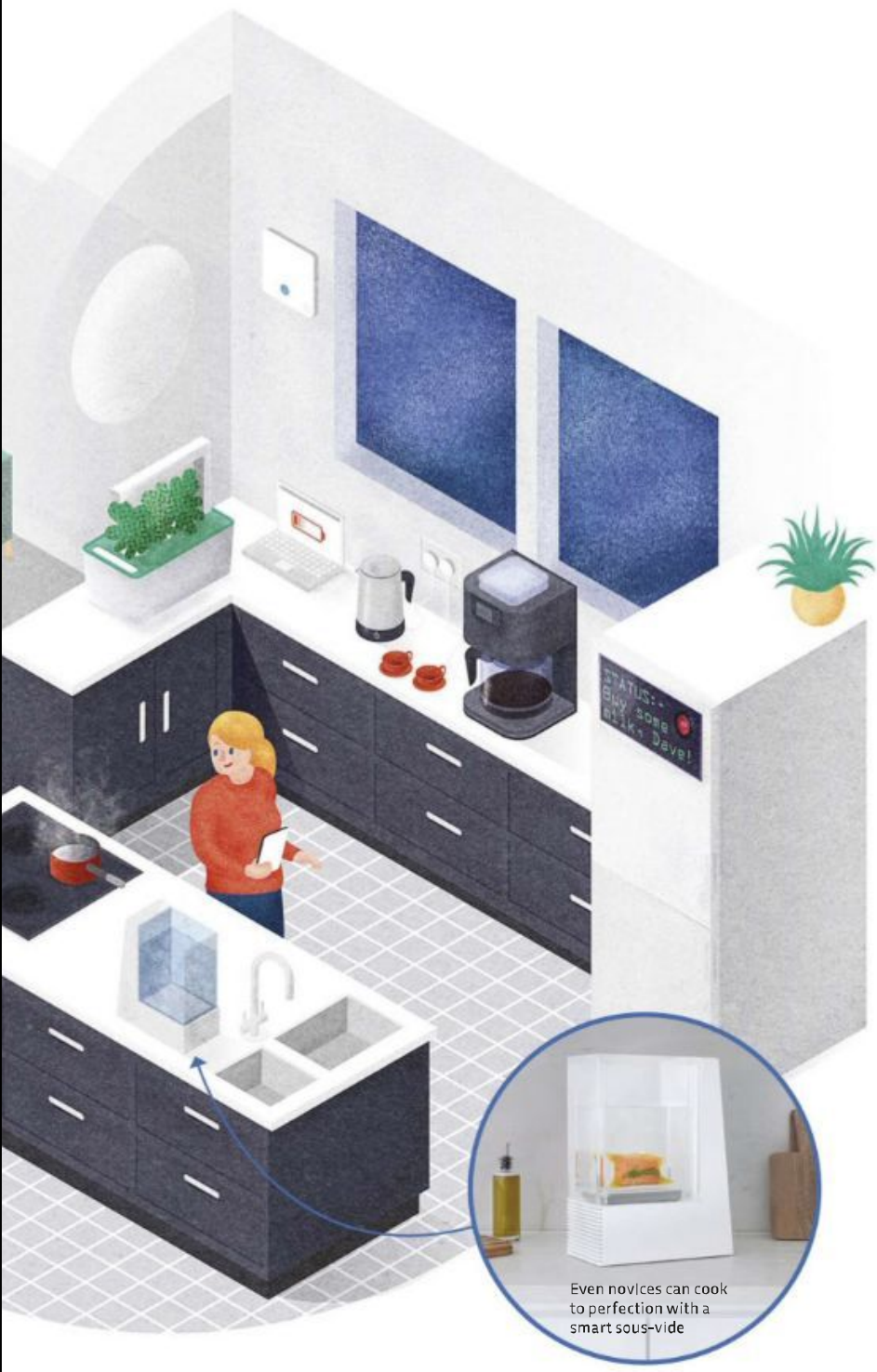
1986
Cathode ray tube TVs dominated living rooms in the 1980s and often had a video recorder nestled underneath. Satellite services arrived on the scene a few years later.

2016
Large flatscreen LCD TVs are the norm today, often equipped with 'smart TV' features and linked up to a recording device, streaming box, or games console.

2036
Expect high-definition televisions of the future to be pretty much invisible until you turn them on, masquerading the rest of the time as a wall or window.



Dyson's 360 Eye uses complex calculations to clean your house



Even novices can cook to perfection with a smart sous-vide

KITCHEN

POWER
Wireless is the future, but even juicing up a smartphone via a charging plate will be old news soon. Companies are already showing off long-range, over-the-air power solutions. Energous WattUp claims to power devices from six metres away. This will mean never charging a gadget again.

COOKING
Sous-vide is one of the best ways to cook food to perfection, but until now it's been expensive and reserved for chefs. Mellow is a smart sous-vide device that will be able to store food in a refrigerated state, weigh it and cook it ready for when you want it. It even has a smart chef that'll learn what foods you like to offer the perfect meal or make suggestions in the future. The next step? Something that will grow and harvest the food, too.

COFFEE
Even making hot drinks is more intelligently handled now. Smarter Coffee, as the name suggests, offers a clever way to make coffee via your smartphone and an app. Select what drink you want, how strong and for how many people; the machine will do the rest, and you'll be notified when it's ready to collect from the kitchen. If you want it for when you wake or arrive home, it can do that, too. More of a tea person? The iKettle heats water to particular temperatures to suit your chosen brew, while its Formula mode will boil water as soon as it hears your baby crying, then keeps it at the perfect temperature for bottles.

FOOD MANAGEMENT
Never run low on food again thanks to Smart Fridge Cam and Smarter Mat. The camera sticks to the inside of your fridge door with suction pads and lets you look inside when you're out shopping. The Smarter Mat can be placed under items like milk in the fridge or rice in the cupboard, and will detect the weight to alert you when you're running low.

GROWING
Growing fresh herbs no longer requires a garden, green fingers or even effort – the Smart Herb Garden automates it all. Just load in plant capsules, fill the tank with water and plug it in, and the Smart Soil and system's sensors will keep water, oxygen and nutrients at optimal levels for perfect growth. You just have to make sure it gets some light, which hopefully isn't too much to ask.

FOOD PREP

1986
All hail the microwave. While they were first introduced in 1967, it was in the 1980s that they became small and powerful enough to bear the load of cooking.

2016
Sous-vide is the new hassle-free cooker. Set the bagged food in the water-filled unit and it'll do the rest.

2036
You'll be able to 3D print and cook your food. Scientists are already showing off 3D printed hamburgers. By 2036 we may no longer grow food but will instead cultivate the right cells to print off our meals.



Sleep better with the Eight tracker

BEDROOM

SLEEP

A decent night's kip is something everyone would like, but at the moment sleep tracking is all that most people can hope for. But a new wave of smart mattresses and covers can not only track sleep, but help improve it too.

The Eight is a cover that slips over your mattress. It tracks 15 factors and then warms or cools the bed accordingly to optimise comfort. Thanks to dual zones, Eight is able to track you and your partner's sleep individually, and improves as it learns.

STORAGE

With space at a premium, storage becomes an art form. Understairs cupboards that slide out are currently a popular option. The future could be even more inventive. Imagine drawers that automatically vacuum-seal your clothes to save on space, or anti-gravity shelves that move up and down as needed.

SURVEILLANCE

Smart homes aren't complete without some sort of camera that can be monitored from a smartphone app. So far we've got Nest Cam, Logi Cam and more. These let parents be alerted to noise or movement in a child's bedroom, or allow residents to add security to their properties without an expensive system.

Cameras are already able to recognise faces and can be set to allow or deny access. The future should go beyond facial recognition with doors able to recognise a combination of gait, smartphone and scents from a person. The result will be a far more trustworthy security system, without the need for keys or even handles.

FURNITURE

With rumours that the next iPhone will be port-free, and wireless charging as standard in lots of smartphones, it's time for furniture to catch up. Ikea sells tables and lamps with built-in wireless chargers, while Starbucks offers a similar feature on its tables: drop your phone in the right spot and it'll juice up.

Ease of use and reduced clutter make this a winner, so expect plenty of smart designer furniture to start appearing this year, too.

SLEEP HABITS

1986
Good sleep was attained from drinking a nightcap and shutting the curtains.

2016
Smart lights can gently ease a person off to the land of nod, while tracking tells them how well they've slept.

2036
Smart mattresses, clever lighting and noise-cancelling devices will create a perfect snoozing environment.

BATHROOM

MIRROR
Other than your phone, the one place you look every morning is the bathroom mirror. Wouldn't it be nice for that mirror to have all your morning alerts from social media, news and email? Samsung has shown off just this with its smart mirrors. They're touch-sensitive, and will display everything you need in one hub while you're brushing your teeth. They even contain cameras so you can virtually try on clothes.

SHOWER
Water falling from a shower is so last century! The future is Nebia. This shower head atomises water to create a cloud of smaller water droplets, which is more immersive than a regular shower. It saves 70 per cent on the amount of water needed and is 13 times more thermally efficient.

TOILET
Toilets are not just for waste – they are wasteful too. Bill Gates is throwing megabucks at cracking the problem of finding a perfect toilet. The solution should be one that saves water, increases recycled drinking water supplies, creates energy from human waste and is cheap to maintain. Good luck, Bill.

THE LOO

1986
A basic porcelain toilet with a flush and perhaps a frilly toilet seat cover was all we could hope for.

2016
Now, in Japan at least, your toilet can sing to you, heat the seat, flush, open, close and even wash you automatically.

2036
Toilets will be able to harvest your waste for water and power. They'll probably be comfier too, which can't be difficult since we're still stuck on plastic seats right now.

WINDOWS
Windows that change their tint automatically aren't new, but a team at the University of Texas has developed glass that's able to block the heat-producing part of light. Thanks to a framework of electrically conductive nanocrystals embedded in a glassy material, near-infrared light can be blocked by adding an electronic charge. Up to 90 per cent of near-infrared light and 80 per cent of visible light can be blocked. This could mean huge energy savings in buildings of the near future.

Luke Edwards is a technology and gadgets writer.

DISCOVER MORE

Keep abreast of all the latest technology with *Click*. Catch up on iPlayer at **bbc.in/1PnLpYC**



Smart mirrors let you stay up-to-date with the latest news while getting ready in the morning





PHOTO: GETTY

COULD YOUR DRIVERLESS CAR CHOOSE TO KILL YOU?

TWO KIDS ARE IN THE MIDDLE OF A MOUNTAIN ROAD. YOUR CAR COULD DRIVE STRAIGHT INTO THEM, OR AVOID THEM BY SWERVING OFF THE SIDE, KILLING YOU IN THE PROCESS. SO WHICH CHOICE SHOULD IT MAKE?

WORDS: HEATHER BRADSHAW-MARTIN
Heather is an automotive software engineer and test driver. She holds a PhD in bioethics from the University of Bristol.

The sound of screeching tyres followed by a bus hurtling directly towards you. It's not exactly something you'd want to come across when cycling up a steep, narrow road. But in March 2015, on Franschhoek Mountain Pass in South Africa, that's just what one cyclist was faced with after a bus driver swerved in an attempt avoid two other cyclists while negotiating a sharp corner. The bus overturned and three passengers lost their lives. In the investigation that followed, the police talked of prosecuting the bus driver for 'culpable homicide', a charge resulting from the negligent killing of a person according to South African law. But what might they have said if the bus had been driven by autonomous software?

The driver was faced with a rare and complicated type of moral dilemma in which they were forced to choose between two bad options. Analysis of the above scenario raises two main questions: the first is to ask whether the accident could have been avoided by better vehicle maintenance, more careful driving, better road design or other practical measures and whether there was negligence in any of these areas. The second is to ask that if the accident was not avoidable, then what was the morally least bad action?

"Driverless cars will be able to stop extremely quickly once they detect a hazard. Also, they will never get drunk"

When thinking about these issues in terms of autonomous vehicles, the first question is relatively easy to answer. Driver software will have faster reaction times and be more cautious and physics-faithful than human drivers, meaning driverless cars will be able to stop extremely quickly once they detect a hazard. Also, they will never show off or get drunk. However, their sensors and image classification processes will remain cruder than human perception for some time to come, meaning they may not recognise or classify unexpected hazards the way humans do. They won't be able to reliably tell the difference between children and adults, for example. Nor will they know whether other vehicles are empty or are carrying passengers.

Some commentators believe that once the technology is perfected, autonomous vehicles could provide us with a completely accident-free means of transport. Yet large-scale statistical analyses, such as those carried out by Noah Goodall at the Virginia Department of Transportation, indicate that this is unlikely. Thanks to the existence of pedestrians, cyclists, and even animals, our roads are too unpredictable for any autonomous system to take everything into account.

So how do driverless cars fit in with the moral question? Firstly, autonomous vehicle driver software won't have had years of real-life experience to learn the nuances of morality through praise, blame and punishment the way a human driver has. Nor will it be able to use its imagination to build on these previous learning experiences.

Imagine a similar situation to the above scenario. A vehicle being driven completely by software and carrying one passenger is travelling uphill around a steep corner on a narrow two-lane mountain road. Two children are riding bicycles down towards it on the wrong side of the road and a heavy truck is approaching in the other lane. To avoid the children, the car can head for the truck or drive off the side of the road, but if it stops the children will hit it. Driving into the truck or off the precipice will likely kill the human passenger but save the children. Attempting to stop could lead to the children being killed if they crash into the car, yet the passenger will be protected. What should the car's software be designed to do?

RARE DILEMMA

Of course, such dilemmas are rare occurrences but they are nevertheless of key concern to engineers



1



2



3

1 Self-driving pods are already being tested in the UK
2 Cyclists are safe when Google's driverless car is on the streets
3 In the Franschhoek accident, the bus driver swerved to avoid two cyclists – but did he have an alternative option?

PHOTOS: CORBIS X2, PRESS ASSOCIATION



To visualise how driverless cars view the world, ScanLAB – a UK-based 3D scanning company – drove a 3D laser scanner through London's streets

"A human driver might instinctively flinch away from a large object like a truck, without being able to process the presence of cyclists"

and regulators. But whereas the human bus driver mentioned above had only a frightening fraction of a second to make a life and death decision, the engineers have hours and hours in the safety of an office to design how the vehicle's driver software will react. Of course, this means that they cannot claim that they reacted 'instinctively' due to time pressure or fear. In the event of an accident, courts will say that the engineers have programmed the software rationally and deliberately and thus expect them to be fully morally responsible for their choices. So what must they consider?

There are three broad schools of thought. One: autonomous driver software may be expected to operate to a *higher* moral standard than a human driver because of the lack of time pressures and emotional disturbances and its greater processing power. Two: it could be expected to operate to a *lower* moral standard due to the sensors' lack of classificatory subtlety and the overriding belief that only humans can act ethically because software cannot be conscious or feel pain. Three: software may be expected to operate to the *same* moral standard as applies to human drivers.

All three options imply that the moral standard expected of human drivers in such dilemmas is definitively known. But when forced to act quickly, humans will often use their instincts rather than conscious, rational analysis. Instincts may be honed through life experience or deliberate practice but they are not under conscious control at the point of application. Our emotions can also influence instinctive action. So a human driver might instinctively flinch away from a large object like the truck, without being able to process the presence of the cyclists. Or, a human with different instincts might act to protect the vulnerable children without recognising their own danger. Such unconsidered reactions are hardly moral decisions that are worthy of praise or blame. So what would moral behaviour require if we set aside the confounding factors of time and emotion?

The study of such questions takes us into the territory of ethical theory, a branch of philosophy concerned with extracting and codifying the morally preferable options from the morass of human behaviour and beliefs. Philosophers have developed logically consistent theories about what the morally preferred actions are in any given situation.

Today, two main contenders exist for the top theoretical approach: consequentialism and deontology. Consequentialist theories say the right action is that which creates the best results. Deontological theories say the correct action is that in which the people's intentions were best, whatever the results. Despite starting with different founding assumptions about what is valuable or good, these two theories agree on the morally preferable action in the majority of common situations. Nevertheless, they do sometimes differ.

MACHINE ETHICS

Both consequentialism and deontology are based on consistent reasoning taken from a small set of assumptions, which is something algorithms can do. So, can we write algorithms that will calculate the best course of action to take when faced with a moral dilemma? Those working in the small scientific field of machine ethics believe that we can. Artificial intelligence researchers Luis Moniz Pereira and Ari Saptawijaya have been collating, developing and applying programming languages and logic structures that capture deontological or consequentialist reasoning about particular moral problems. These programs are limited in scope, but their work suggests that it would be possible to program an entity to behave in accordance with one or other of the major ethical theories, over a small domain. This work is often criticised, not least for not covering the entire range of ethical problems. But a slightly deeper look at moral theory suggests that's inevitable.

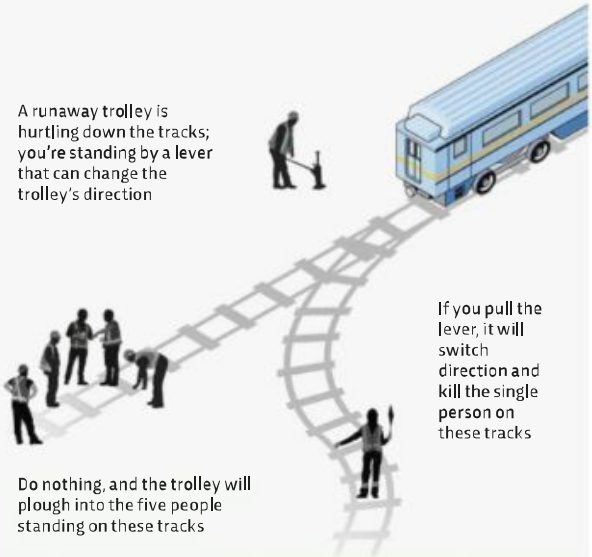
Most cases where the two moral theories agree are easy for courts of law to decide. But there are certain types of cases in which judges must call on the

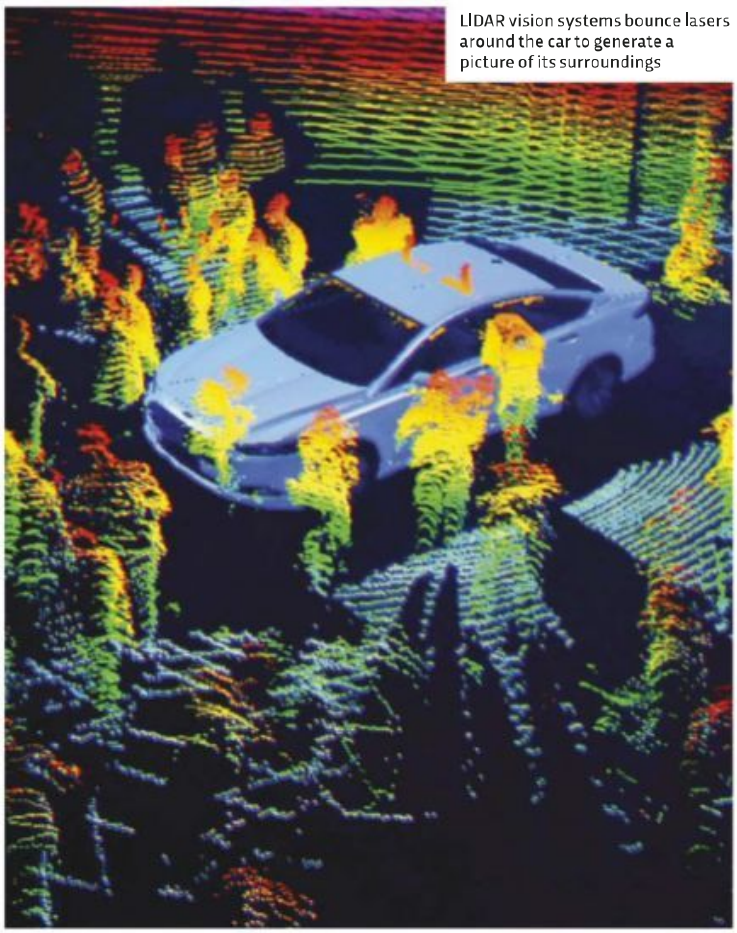
PHOTO: SCANLAB PROJECTS



THE TROLLEY PROBLEM

This popular ethics dilemma makes you choose between killing one person or five, and was first introduced by philosopher Philippa Foot





LIDAR vision systems bounce lasers around the car to generate a picture of its surroundings

wisdom drawn from years of courtroom experience. Examples include trials for war crimes, shipwreck and survival cases, medical law, and also road accidents. Because of their complexity and the moral discomfort they cause, cases such as these attract lots of legal and philosophical attention.

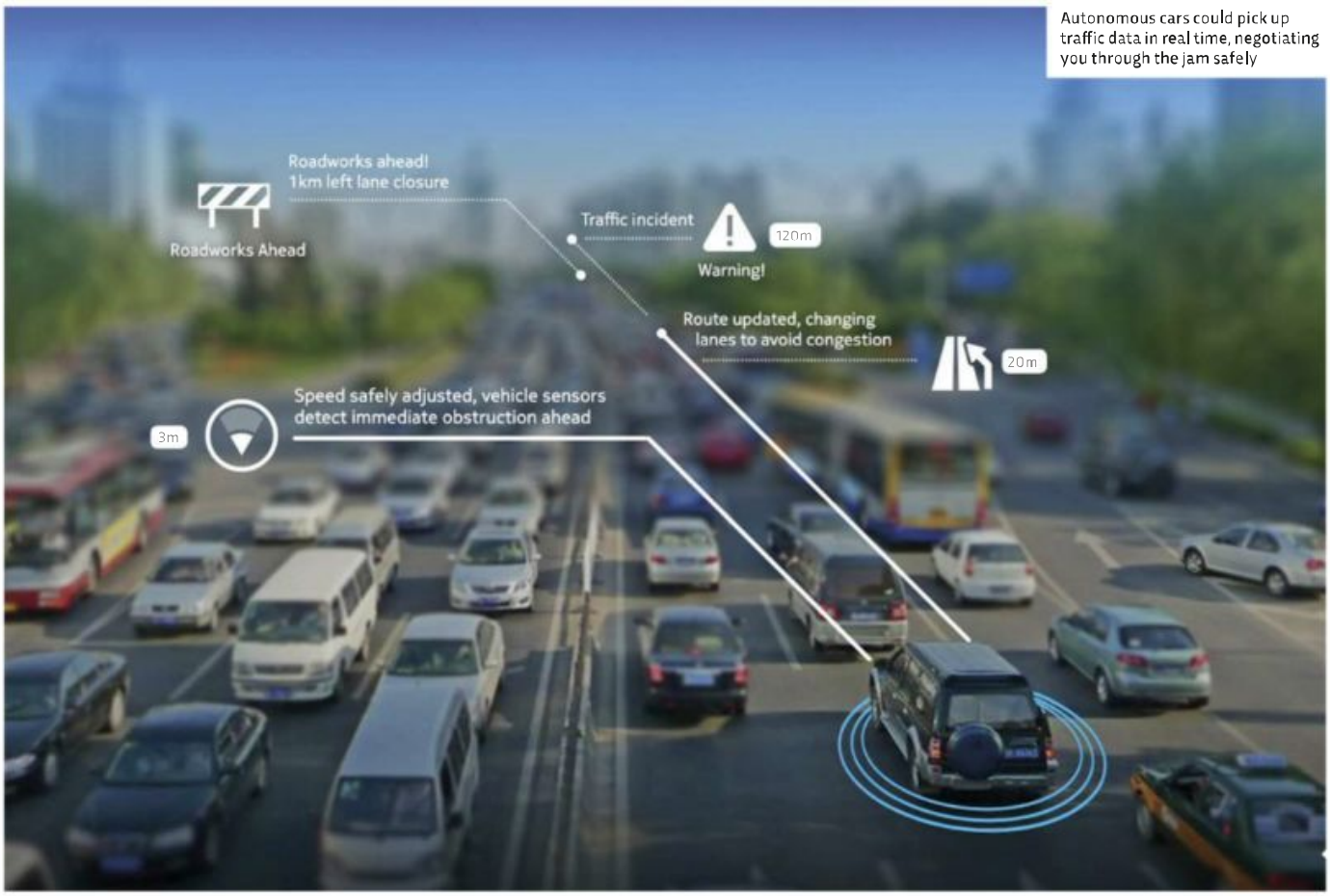
TROLLEY PROBLEM

In ethical theory, complicated moral dilemmas are named 'trolley problems' after a thought experiment that was introduced by British philosopher Philippa Foot in 1967 (see diagram above). The experiment asks you to imagine a runaway trolley (tram) travelling at breakneck speed towards a group of five people. You are standing next to a lever that can switch the trolley to a different set of tracks where there is just one person. What's the right thing to do?

The two main ethical theories disagree about the morally correct course of action in trolley problems. Humans also disagree with which is the best course of action. Studies show that most people will not pull the lever and therefore fall on the side of the deontological theory. MRI scans show that the areas of the brains associated with emotions light up when these people considered the question. Their thinking goes that to pull the lever knowing about the one person on the side track would be to take an action intended to kill the one. Deliberately acting to use one person to benefit five others is considered wrong, irrespective of the outcome. Here, standing by and doing nothing is acceptable because as there isn't an act, there can't be a 'wrong' deliberate intention. The death of the five is only an unintended side effect of doing something perfectly acceptable: nothing. But a minority feels very strongly that consequentialism is preferable and MRI scans of their brains show more stimulation of logical reasoning areas when considering the problem. They would pull the lever because one death is a much better outcome than five deaths, and whether there was a deliberate intention to kill or not is irrelevant – only the outcome matters. Similarly, if we think back to our earlier scenario of the passenger travelling on the mountain road, then consequentialist theory would claim that it makes sense for the car to kill them because two children

"In the world of law, judges have to recognise that some actions they don't agree with are still morally acceptable"

PHOTOS: GETTY, ALAMY



Autonomous cars could pick up traffic data in real time, negotiating you through the jam safely

would be saved. And saving two lives is preferable to saving one.

Acting in accordance with either theory is considered to be ethically principled behaviour. In the world of law, judges have to recognise that some actions they don't agree with are nonetheless still morally acceptable. Respecting others' ethical reasoning is one way we recognise and treat other humans as moral agents with equal status to ourselves. This is an important – although subtle – part of our Western ethical consensus today, because we believe that being faithful to our ethical beliefs contributes towards our well-being.

This makes the problem more difficult for designers of autonomous driver software: there isn't a single moral standard expected of human drivers in these dilemmas. Whichever theory they choose, they will end up offending the morals of ethically principled customers who favour the other theory.

Imagine, purely speculatively, that engineers tend to fall in the consequentialist minority and therefore design consequentialist driver software. However, imagine that the majority of customers are deontological. The engineers would have imposed their own moral preferences on many people who do not share the same ideologies. Being true to one's moral convictions is an important part of human well-being, so we run the risk of inadvertently breaking a moral principle of our societies and adversely affecting the well-being of other people.

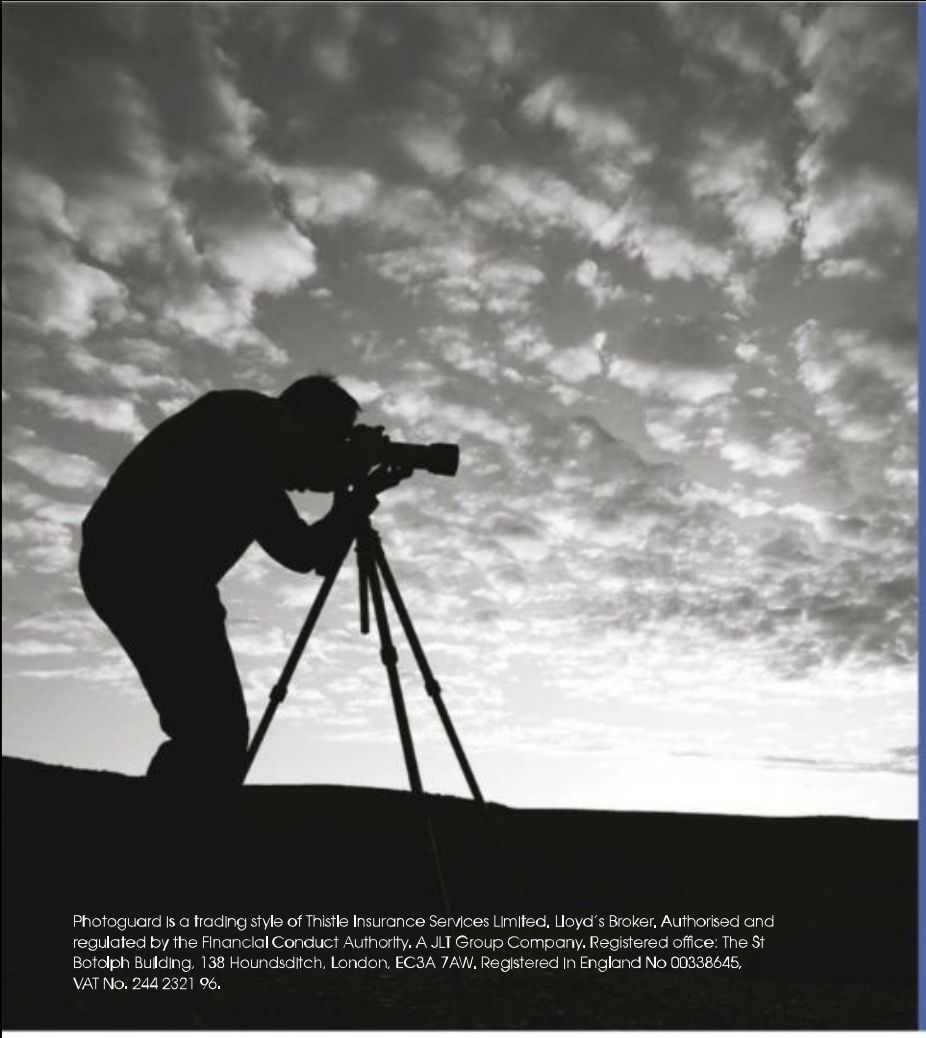
I co-authored a paper with Dr Anders Sandberg, an expert in ethics and technology. In the paper, we suggested we could get around the problem of different principles by developing code that would follow either consequentialist or deontological reasoning in a trolley problem scenario. The passenger could selected their chosen principle at the start of their journey. This would preserve the basis of respect for moral agents that allows our society's ethical and legal system to deal with the two different ways that people make their decisions about trolley problems.

We can't have a piece of code that decides between the theories for us. Human moral preferences seem to be a result of learning through praise and blame, not logic. For now, we have to leave that choice to human users of technology. Until they become moral agents in their own right, autonomous cars will act as what Sandberg has called a "moral proxy" for the users' own human morals. In other words, we will select how they choose to act.

DISCOVER MORE

Watch a clip from *A History Of Ideas* that explains the trolley problem at **bbc.in/11pq3pK**

PHOTO: HERE.COM



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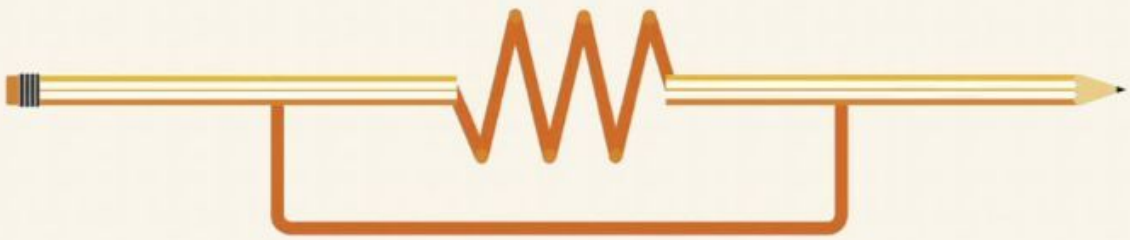
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DR ALASTAIR GUNN
Alastair is a radio astronomer at the Jodrell Bank Centre for Astrophysics at the University of Manchester.



PROF ROBERT MATTHEWS
After studying physics at Oxford, Robert became a science writer. He's visiting professor in science at Aston University.



DR PETER J BENTLEY
Peter is a computer scientist and author who is based at University College London.



LUIS VILLAZON
Luis has a BSc in computing and an MSc in zoology from Oxford. His works include *How Cows Reach The Ground*.

YOUR QUESTIONS ANSWERED

Email your questions to **questions@sciencefocus.com** *or post to BBC Focus Q&A, 2nd Floor, Tower House, Fairfax Street, Bristol BS1 3BN.*

WHY ISN'T EVERYONE AFRAID OF HEIGHTS?

MINNETTE CHAMBERS, ANDOVER

When we're up high, the lack of nearby visual anchors makes our bodies sway automatically – this contributes to the dizzying sensation of vertigo. But most people aren't afraid of heights, not in the sense of having 'acrophobia', which is when the mere thought of falling can bring on a panic attack. The rest of us are either height intolerant, height tolerant or height enjoying. Members of the last group have got used to, or even find pleasure in, the sensations brought on by heights, and many also get a thrill from the associated risks. **CJ**



French climber Alain Robert, aka Spider-Man, climbing a 448m-high building in 2007

PHOTO: GETTY

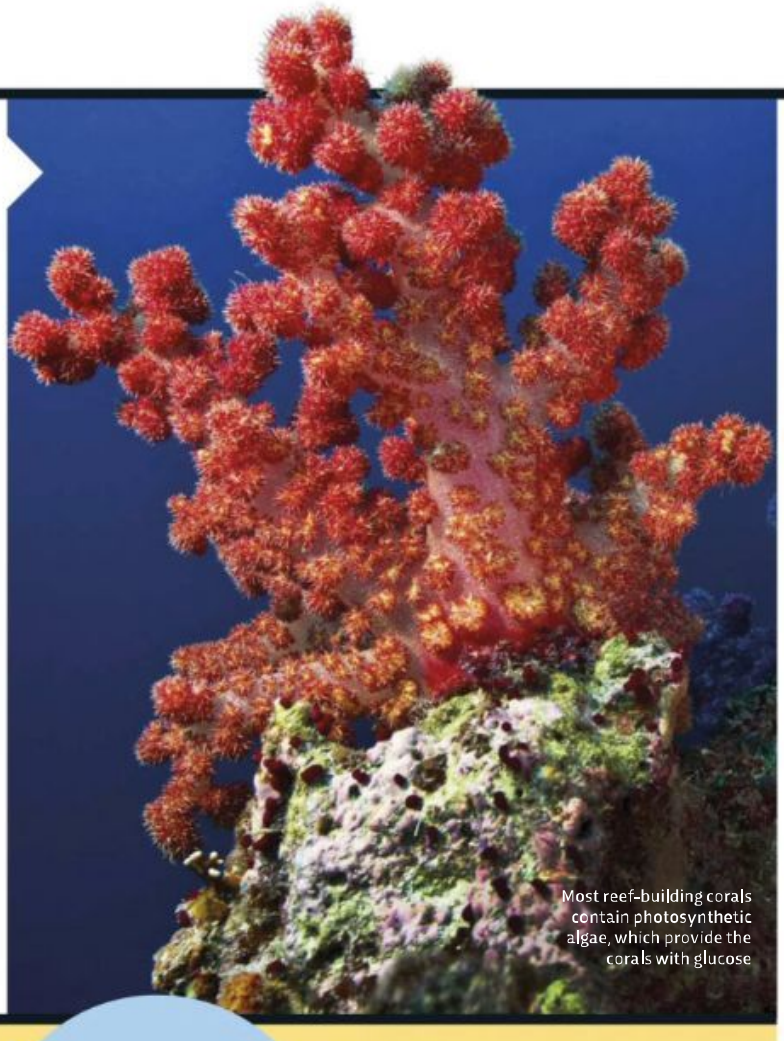
Could we genetically engineer animals to be photosynthetic?

LIZZIE BARKER, LEAMINGTON SPA

There isn't a single gene for photosynthesis, which is the process plants use to produce glucose from the Sun's energy. Plants can photosynthesise because their cells contain chloroplasts, which were originally free-living bacteria that entered into a symbiotic relationship with single-celled organisms about 1.5 billion years ago. Chloroplasts have their own DNA and reproduce inside plant cells, but they also need the plant to provide the right environment.

In 2010, Harvard researchers tried injecting photosynthetic bacteria into the eggs of zebrafish. They found that the bacteria were still alive two weeks after the fish hatched. But the bacteria didn't grow or reproduce and they didn't generate much sugar.

Some animals in nature have partially harnessed photosynthesis. For example, reef-building corals and giant clams contain photosynthetic algae. But photosynthesis only creates sugar. Plants can make all the other biochemical molecules they need, but animals must absorb additional nutrients from food, so photosynthesis could never be a complete replacement for eating. **LV**



Most reef-building corals contain photosynthetic algae, which provide the corals with glucose

QUESTION OF THE MONTH

Could two people who aren't twins have the same DNA?

THOMAS HARRINGTON, WARRINGTON

As a species, humans actually show remarkably little genetic diversity. The DNA of two unrelated people only differs by about one in every 1,000 base pairs; orangutans differ by more than double this amount. Even so, there are three billion base pairs in the human genome, so that's an average of three million genetic differences between any two strangers. Most of these differences are 'single nucleotide polymorphisms' (SNPs), in which a single letter of the genetic code is changed. There are about 20 million known SNPs in the human genome. This means that the odds of someone having the same DNA by chance is like having a deck of 20 million cards, all different, and then drawing the same hand of three million cards twice! **LV**

WINNER!
Congratulations to Thomas Harrington who wins a small EcoSphere pod (£99, **eco-sphere.com**).



IN NUMBERS

1

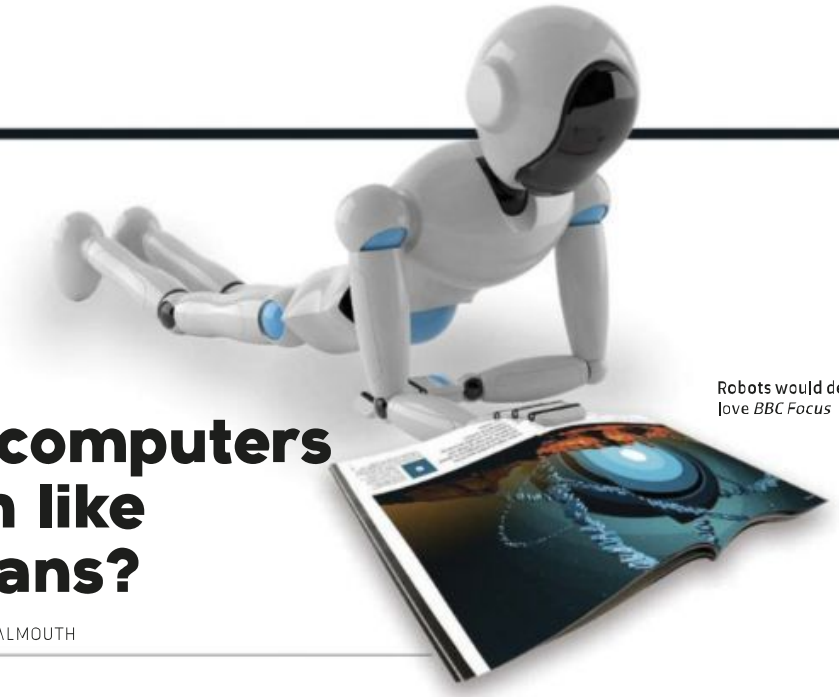
per cent

of UK people actually have coeliac disease, yet 7 per cent believe they have a gluten intolerance

11

km/h

was a *T. rex*'s top speed – even a fairly fit human could outrun it at full pelt



Robots would definitely love *BBC Focus*

Can computers learn like humans?

AUSTIN TOOLE, FALMOUTH

To make computers learn, we use software that simulates neurons connected in networks like in a brain. These networks are trained with data until they can learn patterns or make predictions about what data might come next. Methods like these help computers understand speech or recognise car number plates, so in this respect computers can learn a little bit like humans. But humans are still much better – we can learn complex concepts and a vast number of different ideas.

As we still don't fully understand how brains work, computers are unlikely to be as good at learning as humans for hundreds of years. **PB**

THE THOUGHT EXPERIMENT

COULD I BUILD A HOUSE THAT WOULD SURVIVE A VOLCANIC ERUPTION?



1. LAVA FLOWS

Hawaiian and Icelandic volcanoes produce slow-moving lava. Lava temperature is 700-1,200°C, so it melts or ignites most things. A house on stilts of titanium or tungsten might survive, if the stilts were strong enough to withstand the lava pushing against them.



2. AIRBORNE ASH

Violent volcanoes, such as Vesuvius and Mount St Helens, tend to explode and throw up several cubic kilometres of ash and rock. A 30cm-thick ash layer can be heavy enough to cause roofs to collapse, so you'll need a reinforced roof with a steep pitch to stop the ash building up too much.



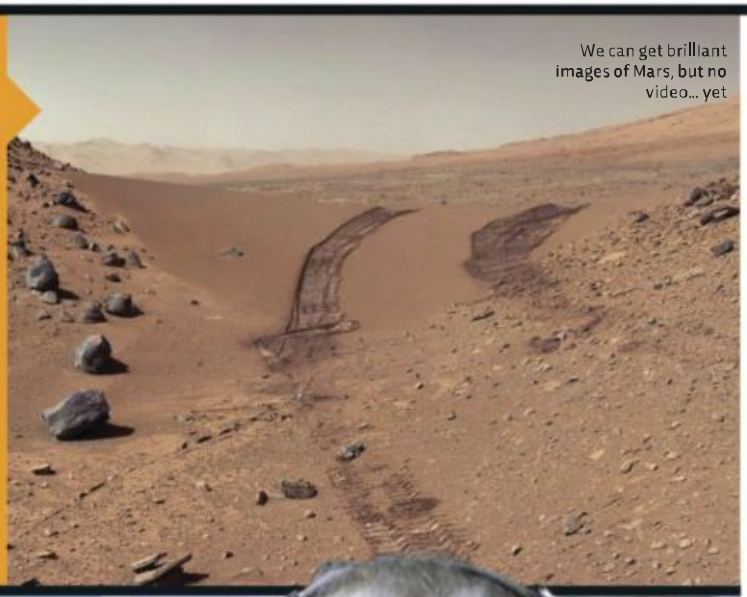
3. POISONOUS GAS

After an eruption, pyroclastic flows can engulf a town in superheated steam and poisonous sulphur dioxide or asphyxiating carbon dioxide. To escape this, you'll need an airtight home with an air supply – preferably underground. But ensure your access hatch doesn't get blocked!

PHOTOS: GETTY, DREAMSTIME ILLUSTRATION: SAM FALCONER

Why do we never see video footage from Mars?

RICHARD O'NEILL, GLASGOW



We can get brilliant images of Mars, but no video... yet

Video footage requires much higher data transmission rates than still images, and it can take several hours for NASA to receive just one high-resolution colour image from Mars. Engineers are looking at switching from radio to infrared communication, because the much shorter wavelength offers far higher data rates. The next generation of Mars landers may then send back HD video imagery direct from the Red Planet. **RM**

Why do humans feel disgust?

SAM AYLING, SURREY



"It's the Kardashians! Turn it off, turn it off!"

When psychologists ask people around the world what they find most disgusting, the same things usually crop up. Mostly these are bodily fluids that have the potential to spread disease, such as vomit, mucus, excrement and blood. The implication, which makes a lot of intuitive sense, is that we've evolved the disgust reaction as a behavioural defence against contamination.

What's particularly intriguing is that this system seems to have been adopted by our moral instinct, which is newer in evolutionary terms. For example, many people say they'd refuse to wear a jumper owned by Hitler, as if they could somehow be contaminated by his evil. **CJ**



Why don't living things rot?

ALEX ROUND, LONDON

They do, we just call it an infection. All living things are under continual attack from bacteria and fungi but they are mostly able to repel these invaders through a combination of the physical barrier of their skin and the cells of the immune system that attack anything that gets inside. If a microorganism manages to gain a foothold somewhere, cells die and the body begins to decompose. It doesn't look quite the same as a rotting corpse because the living cells of the body are constantly battling to repair the damage. Dead things don't resist the invaders. **LV**

PHOTOS: NASA, KOBAL COLLECTION, ISTOCK

Do insects sleep?

CAITLIN HALL, SOUTHAMPTON



Yes. They don't have eyelids, so they don't close their eyes like we do. Cockroaches, however, will fold down their antennae when they sleep, which has the similar purpose of protecting delicate sensory organs.

When asleep, insects aren't just resting – sleeping praying mantises will droop downwards and sleeping bees are harder to startle than those that are having a rest.

Laboratory experiments have shown that fruit flies that are forced to stay awake are slower at learning their way round simple mazes than fruit flies that are allowed sufficient sleep. **LV**

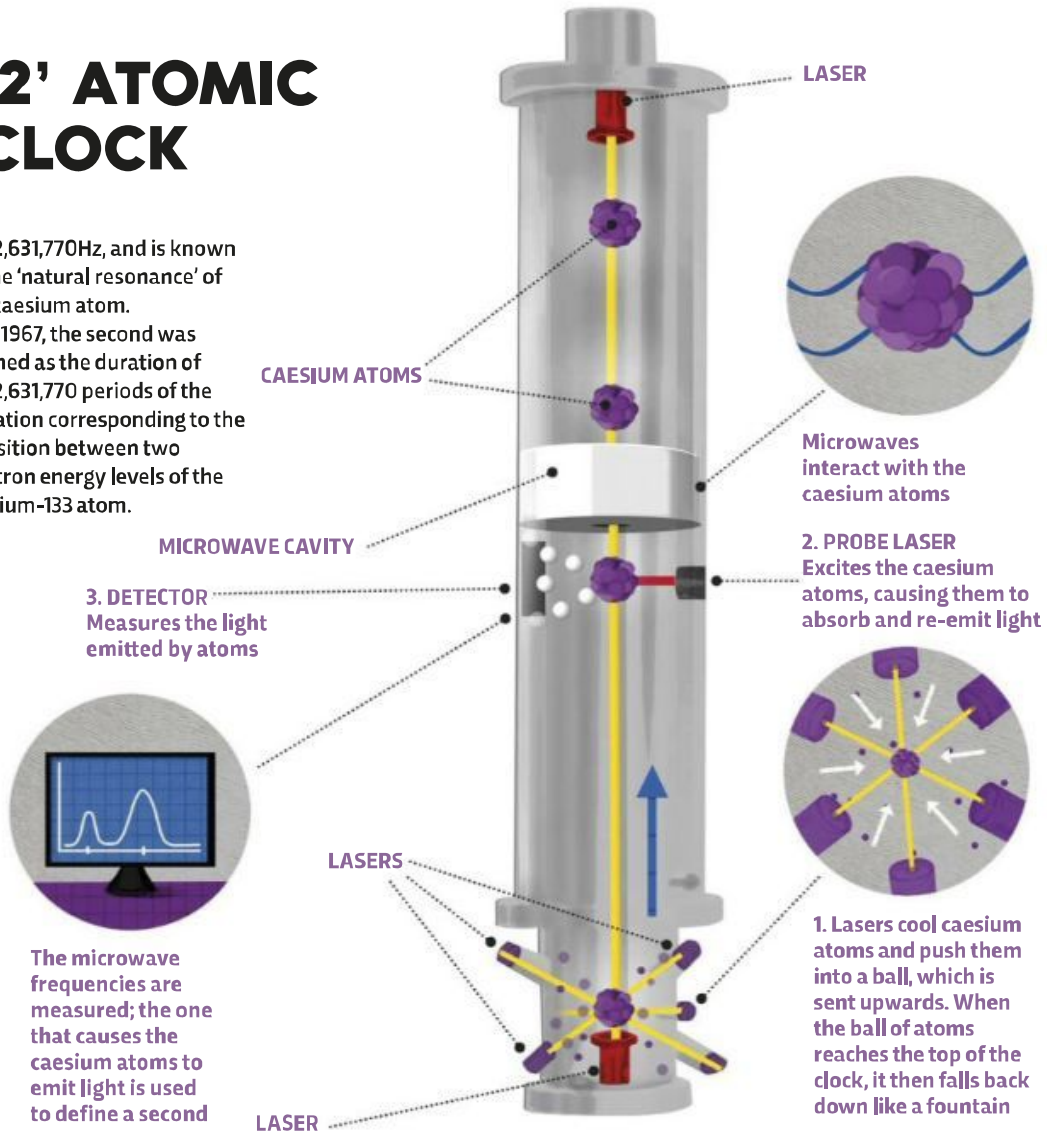
HOW IT WORKS

THE 'NIST-F2' ATOMIC FOUNTAIN CLOCK

One Mississippi, two Mississippi, three... though this way of counting seconds works pretty well for playing hide-and-seek, the atomic clock is vastly superior when it comes to accuracy. It could run for 300 million years and would not stray from perfect time by one second. Whereas counting using words relies on how fast you are speaking, the atomic clock gets its information from electrons jumping around in atoms. Such precision is needed for GPS systems and global telecommunication. Since 2014, The National Institute of Standards and Technology's atomic clock 'NIST-F2' has set the standard time in the US.

So how can atoms define a second? Atoms contain electrons, which change energy levels when hit with radiation at a certain frequency, causing them to emit light. The frequency at which electrons of caesium atoms will change state is 9,192,631,770Hz, and is known as the 'natural resonance' of the caesium atom.

In 1967, the second was defined as the duration of 9,192,631,770 periods of the radiation corresponding to the transition between two electron energy levels of the caesium-133 atom.

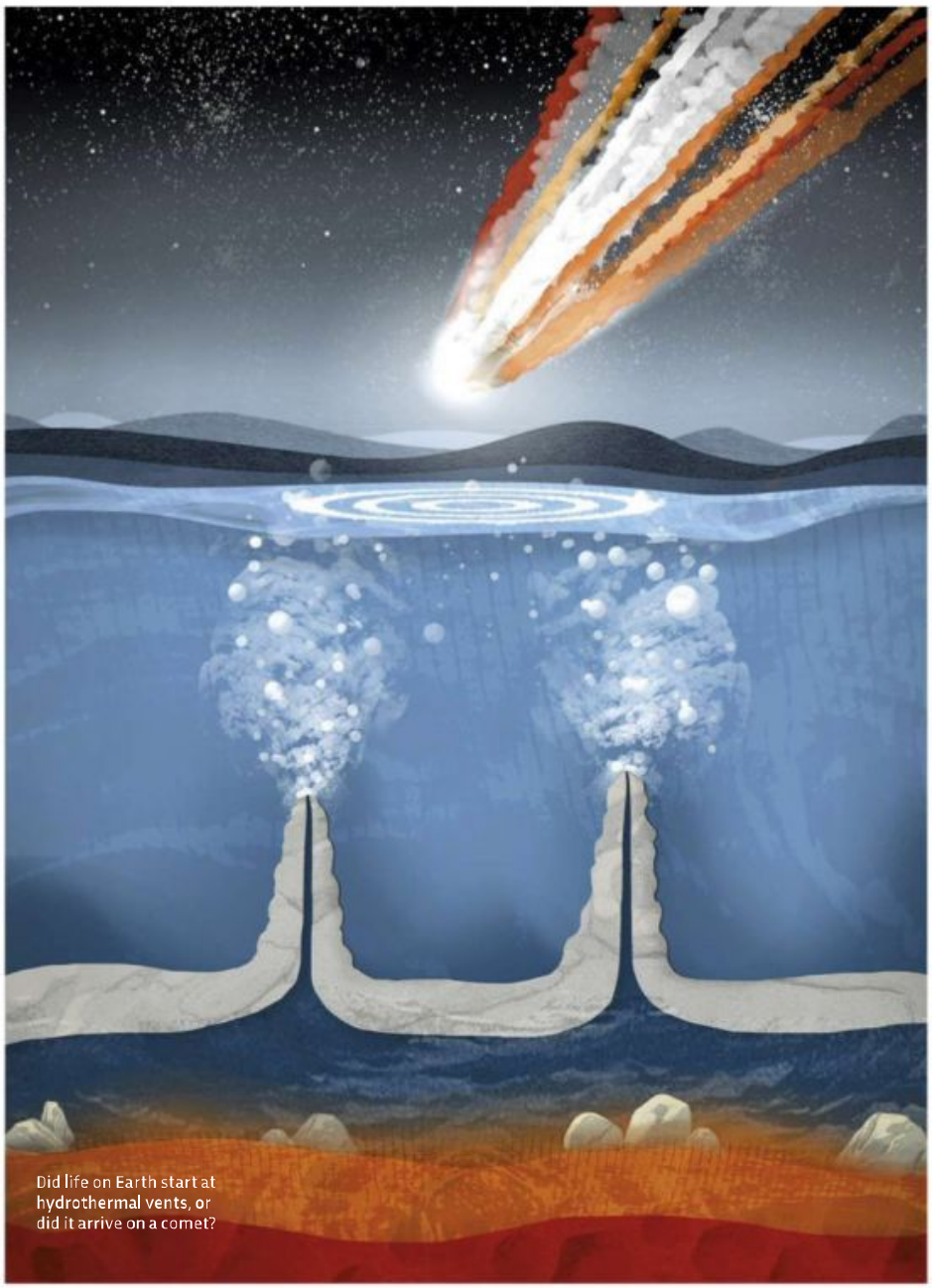


PHOTOS: MATT COLE/FLPA ILLUSTRATION: SAM FALCONER

Q&A

NO EASY ANSWER

How did life on Earth begin?



Did life on Earth start at hydrothermal vents, or did it arrive on a comet?

One hypothesis is that the iron sulphide spewing from deep-sea volcanic vents precipitated into a solid mass with lots of tiny chambers where simple biological molecules could become concentrated and assemble, using energy from iron redox reactions.

The 'panspermia hypothesis', on the other hand, suggests that living cells or spores may have arrived fully formed travelling on comets from outer space. Recent research by Prof John Sutherland at Cambridge University offers a possible compromise between the two: comet impacts may have delivered hydrogen cyanide, which reacted with the hydrogen sulphide already on Earth to form the earliest building block molecules. That then assembled to form RNA. **LV**

How does gravity affect brain function?

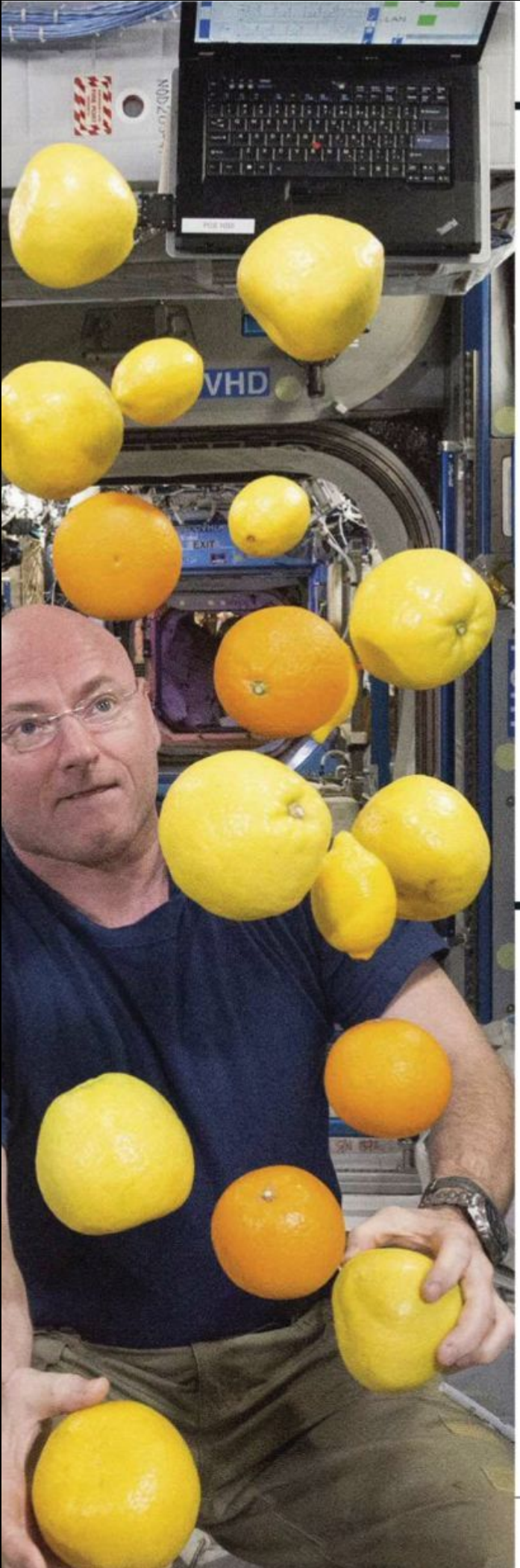
FINBAR MURPHY, ZAMBIA

Our brains have obviously evolved to work in Earth's gravity. Experiments on the International Space Station suggest that our brains have an internal model of how gravity works that we use to accurately predict where a ball will be when we move to catch it. In a weightless environment, the ball moves at a constant speed, instead of a constant acceleration, and so our reactions are slightly off. Gravity also affects the flow of blood through the brain; at accelerations beyond 5g, this begins to affect the brain's electrical activity, producing patterns that resemble epileptic seizures. **LV**



Just don't come crying to us when you find a rogue grapefruit clogging up some vital equipment

PHOTOS: NASA, SCIENCE PHOTO LIBRARY, ISTOCK. ILLUSTRATOR: SAM FALCONER





Does the temperature of the Universe change with time?

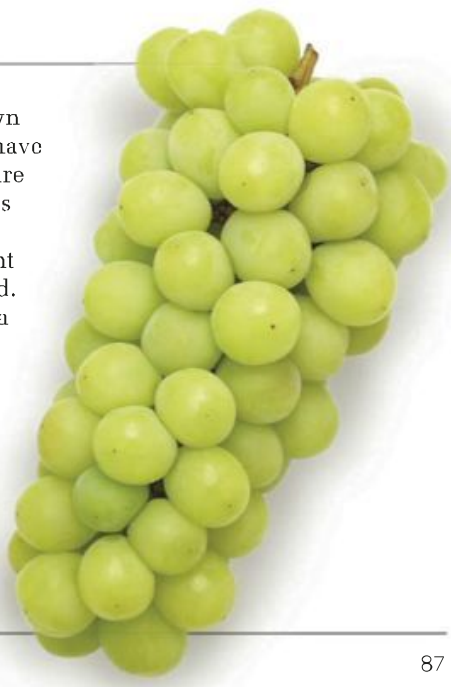
SIMON LENNOX, LONDON

There is a lot of variation in temperature throughout the Universe. The coldest naturally occurring temperature was discovered inside the Boomerang Nebula and is only one degree above absolute zero. The hottest temperatures (not including the Big Bang itself) are likely to be generated in the interactions that create so-called gamma-ray bursts.

But what about the average temperature of the Universe? Astronomers often regard the temperature of the Cosmic Microwave Background (CMB) as the temperature of the Universe. The CMB is a snapshot of the oldest light in the Universe, imprinted on the sky when the Universe was just 380,000 years old. It has a temperature of just 2.735 degrees above absolute zero. The Big Bang theory predicts that as the Universe expands this temperature should drop. This is what astronomers have found by deducing the temperature of the CMB at various distances across the Universe. **AG**

Where do seedless grapes come from?

MYLES SMITH, BROMLEY



Most commercial fruit isn't grown from seed. Even fruits that still have seeds, like apples and cherries, are grown from cuttings because this guarantees that the plant will be genetically identical to the parent plant from which they are cloned. Seedless grapes were originally a natural mutation that prevented the young seeds from maturing and developing a hard coat. And even seedless varieties do sometimes produce small numbers of seeds, which allows new varieties to be crossbred. **LV**

How hard is tooth enamel compared to other materials?

RON PIRANI, MASSACHUSETTS, US



Tooth enamel is mostly hydroxyapatite, which is a mineral form of calcium phosphate. The apatite group of minerals scores a five on the Mohs hardness scale; which makes enamel the hardest biological material. Tooth enamel is harder than steel, but a lot more brittle. So you can't scratch your enamel on metal cutlery but you can chip it by trying to open a beer bottle with your teeth. **LV**

Is new hydrogen being created in the Universe?

CAMPBELL LECKIE, BY EMAIL



There are very few hydrogen atoms being created afresh in the Universe. But there are some. Occasionally, a type of radioactivity called 'proton emission' can produce a 'new' proton and this can form 'new' hydrogen by capturing an electron. Hawking radiation can also produce 'new' protons and hence 'new' hydrogen.

Yet both of these processes are extremely rare and inefficient, so the amount of new hydrogen being created is insignificant compared to the amount created in the Big Bang. Since stars are destroying hydrogen in their interiors, the overall amount of hydrogen in the Universe is decreasing over time. AG

WHAT CONNECTS...

...THE SPACE SHUTTLE WITH A HORSE'S BOTTOM?



1.

The Space Shuttle's solid rocket boosters were manufactured in Promontory, Utah. To get to the launch site in Florida, 3,862km (2,400 miles) away, each one had to make a seven-day train journey.

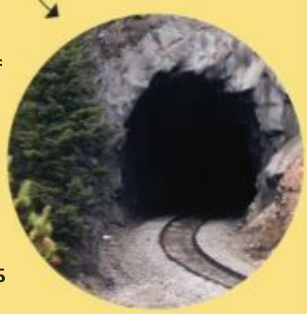
2.

In order to fit through the railway tunnels along the route, the design of each booster segment was limited to a maximum diameter of just 3.66m (12ft).



3.

The width of railway tunnels is determined by the gauge of the railway track. The US uses the standard track gauge of 1.44m (4ft 8.5in).





4.

Early trains were drawn by horses. The track gauge was chosen to allow two horses side-by-side to pull a cart. This standard was kept for steam railways, to allow the wagons to be reused.

PHOTOS: NASA, ISTOCK X2, DAVID BARTON, SCIENCE PHOTO LIBRARY



Fallstreak hole
This cloud phenomenon was captured In Victoria, Australia. They occur when ice crystals form in supercooled water droplets. It is thought that they could be caused by aircraft the low pressure behind the wings and propellers causes the air to rapidly cool.

Q&A

TOP 10

SMARTEST DOG BREEDS

And their 'best in show' wins at Crufts

Source: *The Intelligence of Dogs* by Dr Stanley Coren



1. Border collie
Bred for: herding sheep
No wins



2. Poodle
Bred for: duck hunting
Six wins



3. German shepherd
Bred for: herding sheep
Three wins



4. Golden retriever
Bred for: retrieving waterfowl
No wins



5. Doberman pinscher
Bred for: guarding
No wins



6. Shetland sheepdog
Bred for: herding
No wins



7. Labrador retriever
Bred for: retrieving waterfowl
Three wins



8. Papillon
Bred for: companionship
No wins



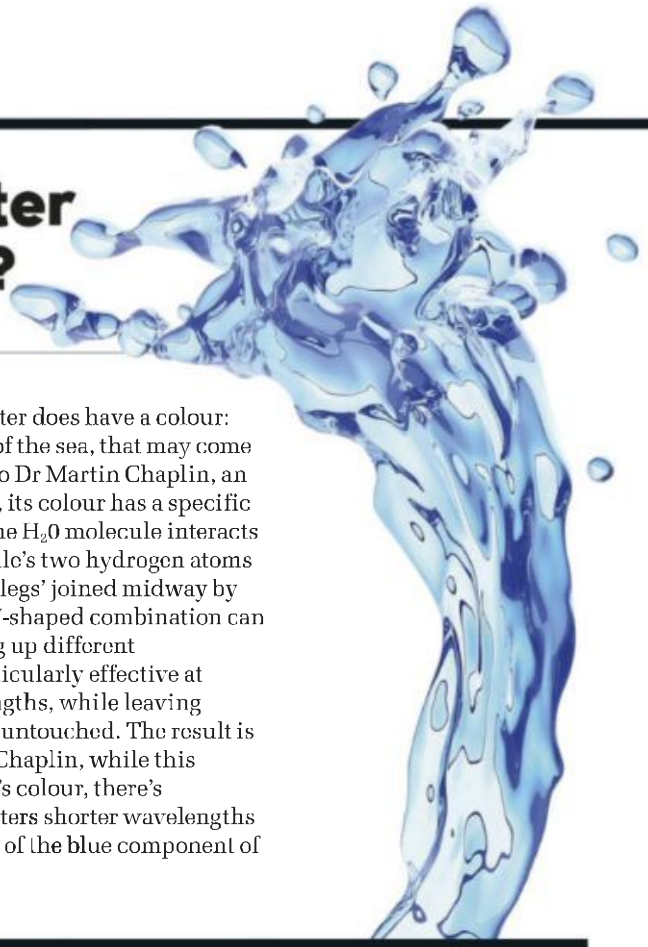
9. Rottweiler
Bred for: driving cattle and guarding
No wins



10. Australian cattle dog
Bred for: driving cattle
No wins

Why is water colourless?

WAEL ALSALLAMI, YEMEN



Lab measurements show that water does have a colour: pale blue. Given the blue colour of the sea, that may come as little surprise. But according to Dr Martin Chaplin, an expert on the properties of water, its colour has a specific cause. Its origins lie in the way the H_20 molecule interacts with incoming light. The molecule's two hydrogen atoms sit at the ends of two spring-like 'legs' joined midway by the oxygen atom. The resulting V-shaped combination can vibrate in various ways, mopping up different wavelengths of light. But it's particularly effective at absorbing longer, redder wavelengths, while leaving shorter, bluer wavelengths fairly untouched. The result is a pale blue colour. According to Chaplin, while this absorption contributes to the sea's colour, there's scattering at work too. Water scatters shorter wavelengths more effectively, leading to more of the blue component of sunlight reaching our eyes. **RM**



Is it possible to delete a sent email?

CLAIRE JACOB, CHELMSFORD

Sadly not. Once sent, the message is out of your control. Although some email software may have a recall or undo, these functions are not doing what you think. Recall will only work if the receiver uses the same email software as you – otherwise the receiver just receives the email followed by a second rather embarrassing email saying 'the sender wishes to recall the previous message'. Undo usually works by delaying the sending of your email for a few seconds, giving you a chance to change your mind before it is sent. There's a Chinese saying: once spoken, even the fastest horse cannot catch your words. The same applies to emails – so be careful what you send. **PB**

PHOTOS: ISTOCK X11, ALAMY X2, GETTY, ESO



Why do earplugs amplify internal noises?

DAVID MELLISH, KING'S LYNN

This is called the occlusion effect. Normally, the sounds of your own breathing, chewing and swallowing are mostly transmitted through the bones of your jaw and skull. These vibrations, especially the lower frequency ones, are dissipated outwards by the shape of your ear. But if you block your ears with your fingers or earplugs, you create a resonating chamber between your eardrum and the blockage. It's not just that inside noises sound louder by comparison with the muffled sounds from outside, there is a real, measurable amplification of up to 20 decibels. **LV**

Why is your reflection upside-down in a spoon?

ELLA SCOTT, LEEDS

Unlike a flat mirror, the curved surface of the spoon's bowl bounces incoming rays back towards a central focus point lying between your face and the centre of the spoon's. In passing through this point, rays from the upper part of your face are reflected downward, while those from the lower part are reflected upward. The result is an upside-down image of your face. **RM**



IN NUMBERS

22 weeks

is the approximate age of a human foetus when the brain's characteristic folds start to appear

1

catalogued piece of space debris has fallen to Earth every day, on average, over the last 50 years

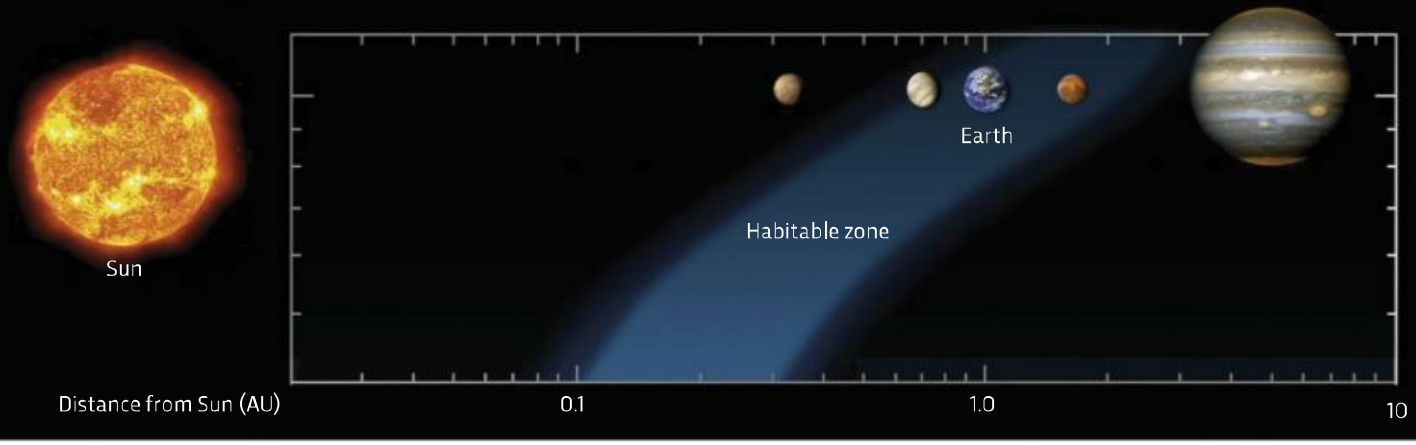
7

per cent a year is the rate at which seagrass is declining

How much closer to the Sun could Earth's orbit get and still be habitable?

ANDREW MOSS, LEICESTER

It is difficult to be precise about the size of the Sun's 'habitable zone' because it depends on many complicated factors, including solar irradiance, atmospheric composition, cloud and weather patterns, the reflectivity (or 'albedo') of the Earth's surface, and so on. But the latest research actually suggests that the inner edge of the Solar System's habitable zone is between 0.95 and 0.99 astronomical units. That means the Earth would become uninhabitable if its average distance from the Sun was reduced by as little as 1.5 million km – which is only about four times the Moon's distance from Earth! AG



How often do large meteorites hit the Moon?

JENNY SMITH, PETERBOROUGH

The Moon is constantly being bombarded with meteorites, but most of them are no bigger than specks of dust. Larger impacts have been observed regularly over the years. In February 2014, Spanish astronomers recorded the impact of a meteorite weighing about 400kg. It was travelling at about 64,374km/h (40,000mph) and probably resulted in a crater 40m wide. Just six months earlier a NASA telescope spotted the impact of a 40kg object. However, the actual yearly rate of these impacts is unclear because astronomers have not yet observed enough of them. AG





Will we ever be able to see through walls?

TOM WILLIS, CANTERBURY

The idea of 'X-ray goggles' that allow us to see through solid walls has been around for decades, but they're a non-starter – not least because X-rays are surprisingly easily absorbed by brick and concrete. A cheaper, safer and more effective approach has now been developed by researchers at the Massachusetts Institute of Technology using wireless signals.

We've all experienced the annoyance of radio reception changing as we move around a room. But Prof Dina Katabi and colleagues at MIT have found a way of exploiting this effect using software that converts the changing strength of wireless signals into images.

Because the wavelength of the signals is relatively large, the resolution is poor, so it's not possible to create realistic images of people. But the team claim the technique is good enough to distinguish individuals based on their physical shape. **RM**

How long is the largest animal intestine?

HARRY BURKE, LEOMINSTER



It's a fairly close contest between the sperm whale and the blue whale. For most whale and dolphin species, the length of their intestines works out as: (body length$^{0.762}$) x 17.02. That comes to more than 150m of intestine in the case of a large sperm whale and possibly as much as 220m for a blue whale. While this sounds enormous, it's actually only seven or eight times the whale's body length. In contrast, a cow has intestines that are 20 times as long as its body – that's 40m for a 2m-long cow! LV

NEXT ISSUE:

Why are some people hairy?
Could my pet catch my cold?
Where does lost body fat go?

ILLUSTRATION: SAM FALCONER

PHOTOS: REINHARD DIRSCHERL/FLPA, GETTY



HELEN CZERSKI... HOW DO SEEDS SPROUT?

"IN SOME PARTS OF A PLANT, PRESSURE CAN BE THREE TIMES THAT OF A BOTTLE OF CHAMPAGNE"



This is the time of year when seedlings start to appear. After planting seeds, I'll find myself going back far too often, checking to see whether they're visible yet. If you keep looking, you'll see the seedlings pushing aside small bits of soil and tiny stones as they grow. They're not just winding around obstacles – they're shoving them. The more you think about it, the odder it seems. Without any muscles, how does such a tiny plant create enough force to push anything?

When a seed starts to germinate, the seed case cracks open and new plant cells start to grow. The seedling has to rely entirely on the energy stored in the seed until it can reach the surface and start collecting solar energy using its leaves. But it's got water and nutrients, so off it goes. The trick to the pushing is built into the structure of every cell. Each has a cell membrane – a bag to keep itself in – but it also has a stronger container outside called a cell wall. The cell wall is made of cellulose, meaning that it's flexible but not stretchy.

I'm currently waiting for my tomato seedlings to appear, but they're busy below the ground at the moment. As well as growing new cells, they're pumping water into an inflatable sac inside each cell. This sac is called a vacuole, and it's filled to bursting but the cell keeps on pumping. The reason it doesn't burst is that it's held in by the cell wall. The extra water being pumped in doesn't make the cell bigger – instead it boosts the pressure on the inside, making the cell sturdy. Instead of being flimsy and floppy, it's now a strong brick.

The pressures that a plant cell can generate are astonishing. In a seedling, it's probably only three or four times as great as atmospheric pressure. But in some parts of a mature plant, it can reach 20 atmospheres – almost three times the pressure in a bottle of champagne. And it is this pressure that shoves the soil aside.

Plants are held up by water pressure, and we're most aware of this when plants wilt. When soil becomes dry in the summer, plants may not have enough water to keep the pressure sufficiently high. And so the cells lose their structural strength and start to sag. If you put wilted lettuce into water, it'll soon pump water back into its cells, making it strong and crisp again.

As my seedlings are pushing themselves through the soil, they've also got a piece of armour protecting them. The first two plant leaves, sometimes still in their seed case, are curled up at the top of the new shoot. As the cells in the new plant inflate and push upwards, these two leaves take the brunt of the push back from the surrounding soil, forcing their way through. Once the seedling has reached the surface, it can cast off the seed case, open up the two new leaves, and become a self-building solar-powered factory.

Seedlings popping out of the soil is always exciting. But part of that excitement for me is the appreciation of the elegant mechanism that has pushed them out of their dark hidey-hole. Even a tiny seedling is a hydraulic marvel. And better still, in a few months, there will be tomatoes!

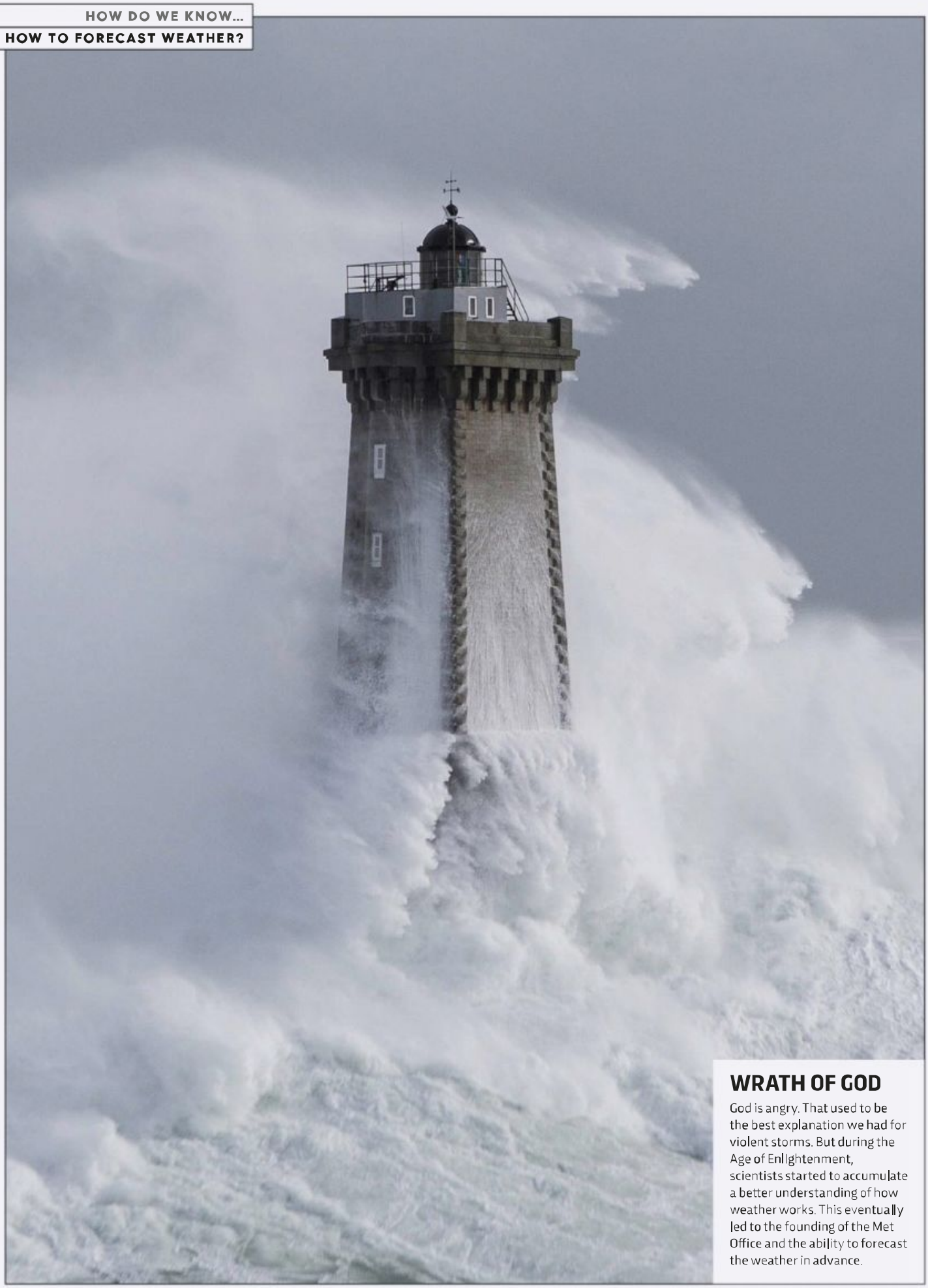
Dr Helen Czerski is a physicist and BBC science presenter whose most recent series was *Colour: The Spectrum Of Science*.

DISCOVER MORE

Did you miss *Colour: The Spectrum Of Science*? You can buy all three episodes of the series In the BBC Store at **store.bbc.com**

NEXT ISSUE: SHAMPOO CONVECTION

MAIN ILLUSTRATION: MATT CLOUGH PORTRAIT: KATE COPELAND



WRATH OF GOD

God is angry. That used to be the best explanation we had for violent storms. But during the Age of Enlightenment, scientists started to accumulate a better understanding of how weather works. This eventually led to the founding of the Met Office and the ability to forecast the weather in advance.

PHOTO: CORBIS

HOW DO WE KNOW...

HOW TO FORECAST THE WEATHER?

Attempting to predict the vagaries of the chaotic, turbulent atmosphere has been an ongoing endeavour since the 1800s

WORDS: PETER MOORE

During an early meeting of the newly formed Royal Society in 1663, a scheme was proposed by John Wilkins, the old master of Trinity College, Cambridge. Why didn't they, he suggested, make a study of the weather in order to build "an art of prognosticating the changes"?

It was a bold suggestion. The weather was an elusive and chaotic force that was barely understood. No one knew how clouds stayed aloft, or where storms came from; what dew was or how rain was formed. Most believed that weather was a divine force beyond all study. Some reminded Wilkins of Elizabeth I's courtier John Dee, who acquired such a skill in foretelling it that he was accounted a witch.

This was where the science of prediction stood at the beginning of the Scientific Revolution. It was deemed too complex or dangerous by the Royal Society to be worthy of study. Yet at the same time it was nothing new. For as long as history stretches back there have been accounts of weather prediction. The Bible speaks of red sky at night, while The Tower of the Winds in Athens was built in 50 BC to help visitors predict the weather according to wind direction and its associated deity.

Then there was weather lore, the ever-evolving set of informal knowledge that was handed down the generations. From the 18th Century onwards this weather wisdom was increasingly collected in books like *The Shepherd Of Banbury* or Thomas Forster's *Pocket Encyclopaedia*. Forster recorded how ants bustling over their hills or swallows skimming across lakes dipping their wings in the water were both signs of rain. Larks and cranes would soar high in fine weather. Dolphins gambolled near boats before a storm, and were therefore regarded as unlucky omens for sailors.



↑ Elizabeth I was impressed with John Dee's scientific skills, and he became one of her advisers

For years, such observations were the best that people had. Despite the invention of the barometer and thermometer during the 17th Century, no clear atmospheric laws had ever been derived from them. Advances remained elusive until the 1800s, when atmospheric physics began to take shape.

A NEW SCIENCE

A pivotal moment came in the USA in 1821 after a fierce hurricane hit the eastern

PHOTO: WELLCOME TRUST IMAGE LIBRARY

coast. Travelling amid the wreckage, a New York businessman called William C Redfield noticed something odd. In Connecticut, the trees had been blown down pointing in a northwesterly direction. But in Massachusetts they had fallen to the southeast. This suggested to Redfield that the winds had twisted 180 degrees in just 70 miles. There was no theory to account for this.

A decade later Redfield published one of the classic texts in the history of meteorology, *Remarks On The Prevailing Storms Of The Atlantic Coast*. Based on a decade's contemplation and research, he unveiled his idea that storms were not simply chaos, but progressive and orderly 'giant whirlwinds' that flew along storm paths. He illustrated his arguments with examples of hurricanes forming in the Atlantic and skimming along eastern coast of the US, showing how the winds twisted anticlockwise about a central vortex as they went. For the first time, people could visualise the storm from above.

Redfield's ideas rejuvenated the study of meteorology, suggesting to others that the atmosphere was a puzzle that might be solved. Over the following decades his work was refined in a series of important contributions. US meteorologist James P Espy demonstrated mathematically how clouds were formed from columns of rising air (now called thermals), which reached a certain altitude before releasing their latent heat. English scientist and merchant captain Henry Piddington proposed that the word 'cyclone' should be adopted as a standard name for Redfield's whirlwinds. Armed with this new sense of how air was moving, the Dutch meteorologist Buys Ballot coined his law in 1857: "In the northern hemisphere, if a person stands with his back to the wind, the atmospheric pressure is low to the left, high to the right." This is because wind travels anticlockwise around low pressure zones.

This jolt forwards in theory dovetailed with two vital technological innovations. The first was a weather map. Though seemingly an obvious tool, none existed until the early 19th Century. One of the first attempts was made by US professor Elias Loomis. His map showed weather over the US during a storm on 3 February 1842. He sourced data from across the country, then drew lines of equal pressure – forerunners to today's isobars – as well as wind direction and weather type.

Of greater significance was the invention of the electromagnetic telegraph, meaning data could be quickly transmitted across massive geographic areas. Soon, Redfield was lobbying in the *American Journal Of Science* for telegraphed weather reports, and this vision was made a reality in 1848, when London's *Daily News* became the first paper to publish telegraphically sourced weather dispatches in real time.

THE FIRST FORECASTER

Before long, these advances were being turned to practical use by Robert FitzRoy, the remarkable head of the newly formed Meteorological Department in London. From the moment of his appointment, FitzRoy was a man in a hurry. He established a weather network on the British coast. He formulated a new grid system for plotting historical weather data over a geographic space,

THE KEY EXPERIMENT

Scientist: Lewis Fry Richardson

Date: 1922

Aim: To predict the weather

Lewis Fry Richardson dreamed of setting up a forecasting factory and so he resolved to establish an experiment to test his idea. He sourced a set of sound meteorological data from 20 May 1910 and set out to complete a full working example of a mathematical forecast for his book *Weather Prediction By Numerical Means*.

At this point, WWI intervened. Richardson was a Quaker and a pacifist and so refused to enlist. Instead he volunteered for the Friends' Ambulance Service and was sent to the Western Front in France. There, in snatched hours over a six week period between his medical duties, he worked on the meteorological calculations for 20 May 1910. Later, he wrote that his office was "a heap of hay in a cold, wet rest billet". At one point, Richardson's entire manuscript was lost during a battle, but it emerged again some months later underneath a heap of coal.

The results of Richardson's forecasting experiment were published in 1922. Ostensibly his effort was a failure. He had forecast a "large and erroneous rise in pressure by 145 millibars", but this had not materialised in reality. Regardless, Richardson published the details of his experiment, providing future scientists with a model. Today, the sort of calculations that Richardson worked on in the trenches form a fundamental part of forecasting science.



↓ Artist's impression of Lewis Richardson Fry's weather forecasting factory

ILLUSTRATION: STEPHEN CONLIN

TIMELINE: WEATHER FORECASTS

We have been fascinated by the weather for centuries. But it is only relatively recently that our knowledge has moved from folklore to science

c.50 BC

circa 50 BC
The Tower of the Winds is built in Athens. Each wall of this octagonal building bears an image of one of the Ancient Greek wind deities.

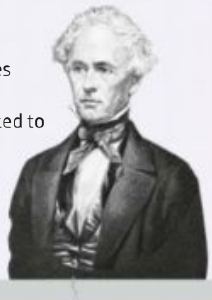


1843



1843
Elias Loomis presents his paper *On Two Storms Which Occurred In February 1842*. It includes the first developed, colour coded weather charts.

WILLIAM REDFIELD (1789-1857)
This New York businessman studies storms in the 1820s and 1830s, demonstrating that they all operated to the same scientific principles. He later becomes the first president of the American Association for the Advancement of Science.



1861

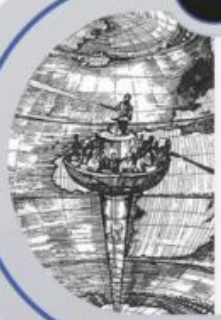


1861
Two years after the *Royal Charter* steam clipper is sunk in a powerful storm, Robert FitzRoy issues Britain's first telegraphed storm warnings and weather forecasts.

ROBERT FITZROY (1805-1865)
In the 1830s, FitzRoy captains the HMS *Beagle*. In 1854 he becomes head of the Meteorological Department in London later the Met Office where he constructs the world's first forecasting system.



1913



1913
Shortly after beginning work at the Eskdalemuir Observatory, Lewis Fry Richardson has his grand idea of a 'forecasting factory', with human computers performing the role of machines.

LEWIS FRY RICHARDSON (1881-1953)
This English mathematician comes to meteorology in 1913 with his appointment as superintendent of the Eskdalemuir Observatory in Scotland. During the next decade, he carries out pioneering work into numerical weather prediction.



VILHELM BJERKNES (1862-1951)
This Norwegian physicist founds the Bergen School in 1917, with the aim of unifying meteorology and putting the subject on a firm theoretical footing. He mentors many influential meteorologists, including his son Jacob Bjerknes, Halvor Solberg and Carl Gustaf Rossby.



1944

1944
Perhaps the most significant weather forecast in history is issued by Group Captain James Stagg on 6 June (D Day). He identifies a break in the stormy conditions that allows the Allied invasion fleet to cross the Channel.



EDWARD LORENZ (1917-2008)
In 1961, this US meteorologist runs a forecasting model on his Royal McBee LGP 30 computer when he notices that a tiny change to input numbers creates a huge discrepancy in the outcome. He calls it 'chaos theory'.



2014

2014
A £97m computer is ordered for the Met Office. It has 120,000 times more memory than a top end smartphone and can process enormous amounts of data.

PHOTOS: GETTY X4, ALAMY X2, UNIVERSITY COLLEGE LONDON



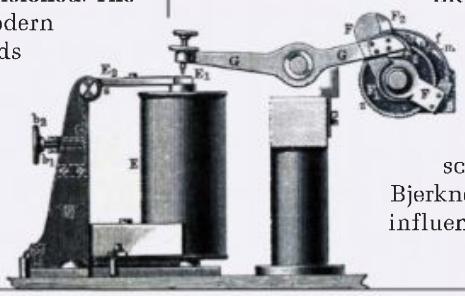
↑ Clouds were first classified in the 19th Century, with illustrations like these appearing in 'cloud atlases'

called 'wind stars'. And he improved upon Loomis's weather map.

But FitzRoy's real interest lay in prediction. After a vicious autumnal gale in 1859 and the wreck of a gold-laden ship, *The Royal Charter*, FitzRoy seized his chance. He won government support for his storm warning system. It meant sourcing weather data from about 20 stations on the coast, analysing it in London, then spotting a storm if he could. If bad weather was detected, a message was relayed to the relevant station, and a drum was hoisted in the harbour in warning.

Within months, FitzRoy's scheme had evolved into general weather predictions for the two days ahead. The first of these 'forecasts' appeared on 1 August 1861. They ran for several years, and turned FitzRoy into a celebrity. Queen Victoria herself requested personalised forecasts when she crossed to the Isle of Wight, while to others he became known as the 'Clerk of the Weather'. But with few staff, an enormous workload and a hostile press, FitzRoy's work was always fraught. Exhausted, depressed and drowned by his own ambition, FitzRoy committed suicide in April 1865. His weather forecasts went soon after.

From today's perspective, FitzRoy's attempts at forecasting were noble yet flawed. Many more observations were needed for system that he envisioned. The first glimpse of modern forecasting methods would not appear until the start of the 20th Century, in the Norwegian town of Bergen.



↓ The telegraph revolutionised weather reporting as it allowed meteorologists to quickly send information across vast distances

The Bergen School holds a pre-eminent place in the history of meteorology. It was founded in 1917 by physicist and meteorologist Vilhelm Bjerknes and then developed by his son Jacob Bjerknes and a list of brilliant others. They sought to bring scientific rigour to meteorology like never before. Their work was shaped by WWI which, by 1917, had deprived Norway of access to British storm warnings, and left it with severe food shortages. Sensing an opportunity, Bjerknes approached the Norwegian government with an offer to support the nation's farmers with meteorology insight.

Bjerknes seized the opportunity to set up a better observation network. In western Norway, the density of meteorological stations was increased tenfold, with the resulting data that poured into the centre in Bergen subject to intense physical scrutiny. Much of this data was plotted onto maps, and they brought a new sophistication to the old field of large-scale meteorology. Jacob Bjerknes, in particular, was influential in defining the anatomy of Redfield's cyclones. In November 1918 he submitted his manuscript *On The Structure Of Moving Cyclones*, which graphically represented sharp boundaries between the cold and warm air. Soon, these boundaries would be given the title of 'fronts'. The work of the Bergen School would provide a model for studying weather systems throughout the world.

THE WEATHER FACTORY

Working at the same time as the Bergen School was a mathematician called Lewis Fry Richardson, who joined the Met Office in 1913.

Soon after his appointment, Richardson conceived a vision of a 'forecast factory' that ran along mathematic principles. Richardson's vision took an architectural form. It comprised a huge hall, filled with rows of human computers who were each responsible for a specific calculation. Once the 'computer' had completed their atmospheric calculation, they would pass their work to the next person in the sequence. The result would be a mathematically precise weather forecast. In his *Weather Prediction By Numerical*

PHOTO: SCIENCE PHOTO LIBRARY, ALAMY

GLOSSARY

Cold front
The leading edge of a cool mass of air that displaces warm air from the ground. It is typically associated with rain.

Ensemble forecasting
The practice of running a specific weather forecast numerous times with varying initial conditions to test the predictability of the atmosphere at a given moment.

Nowcasting
A term coined by Met Office scientist Prof Keith Browning to describe short term forecasts that are updated frequently.

Synoptic chart
A map that simultaneously shows various attributes of the atmosphere at a given moment.

Troposphere
The lowest layer of Earth's atmosphere and the space in which nearly all organic life lives and almost all weather occurs.



←BBC weather reporter Michael Fish's blunder surrounding the 1987 hurricane led to major improvements in forecasting

Process, Richardson said that 64,000 human computers would be needed. A more recent calculation has put the number closer to a quarter of a million.

Richardson nursed his ideas while serving as an ambulance driver behind the trenches during the Great War. With data from Bjerknes, but no 64,000 clerks to assist him, he set off on the heroic endeavour of calculating the required results himself. He snatched every moment he could, essentially establishing his own computerised forecast model as the shots flew around him.

Richardson's ideas cleaved a new path for forecasting in the 20th Century. With the arrival of the computer age in the 1950s, the sort of numerical weather prediction that he had imagined became viable. Models that utilised Newton's second law of motion, as well as the laws of thermodynamics and applied physics, were developed, processing data from an increasing number of land and airborne stations. Likely scenarios were projected onto more detailed grids and maps – descendants of those conceived by FitzRoy and Loomis long before.

Nowadays, all major forecasters rely on numerical weather prediction (NWP) models, which are processed by supercomputers. The Met Office got its first computer in the 1950s – it apparently borrowed one from J Lyons, the tea and cake company – and over time these have become increasingly powerful, able to handle more complex models and higher numbers of calculations. The latest Met Office supercomputer was announced in 2014 at a cost of £97m. It can perform more than 16,000 trillion calculations per second and weighs the same as 11 double-decker buses.

But for all this, weather forecasting can never be an exact science. One of the great discoveries of the 20th Century was Edward Lorenz's chaos theory: his realisation in 1961 that the smallest variation in input can have an enormous effect on output. The triumph of chaos theory gave forecasters yet another challenge to face. Weather forecasting is, just as those at the Royal Society in 1663 suspected, the most difficult of scientific arts.



↓ The familiar isobars we see on today's weather maps show regions of equal pressure

PHOTO: BBC, SCIENCE PHOTO LIBRARY

Peter Moore is a historian, lecturer and author of *The Weather Experiment*.

DISCOVER MORE

Author Iain Sinclair presents an episode of *Archive On 4* that discusses the British obsession with the weather at **bbc.in/PyqYr0**

NEXT MONTH: UNDERSTAND FORENSIC SCIENCE

OUT THERE

WHAT WE CAN'T WAIT TO DO THIS MONTH

MARCH 2016 | EDITED BY JAMES LLOYD

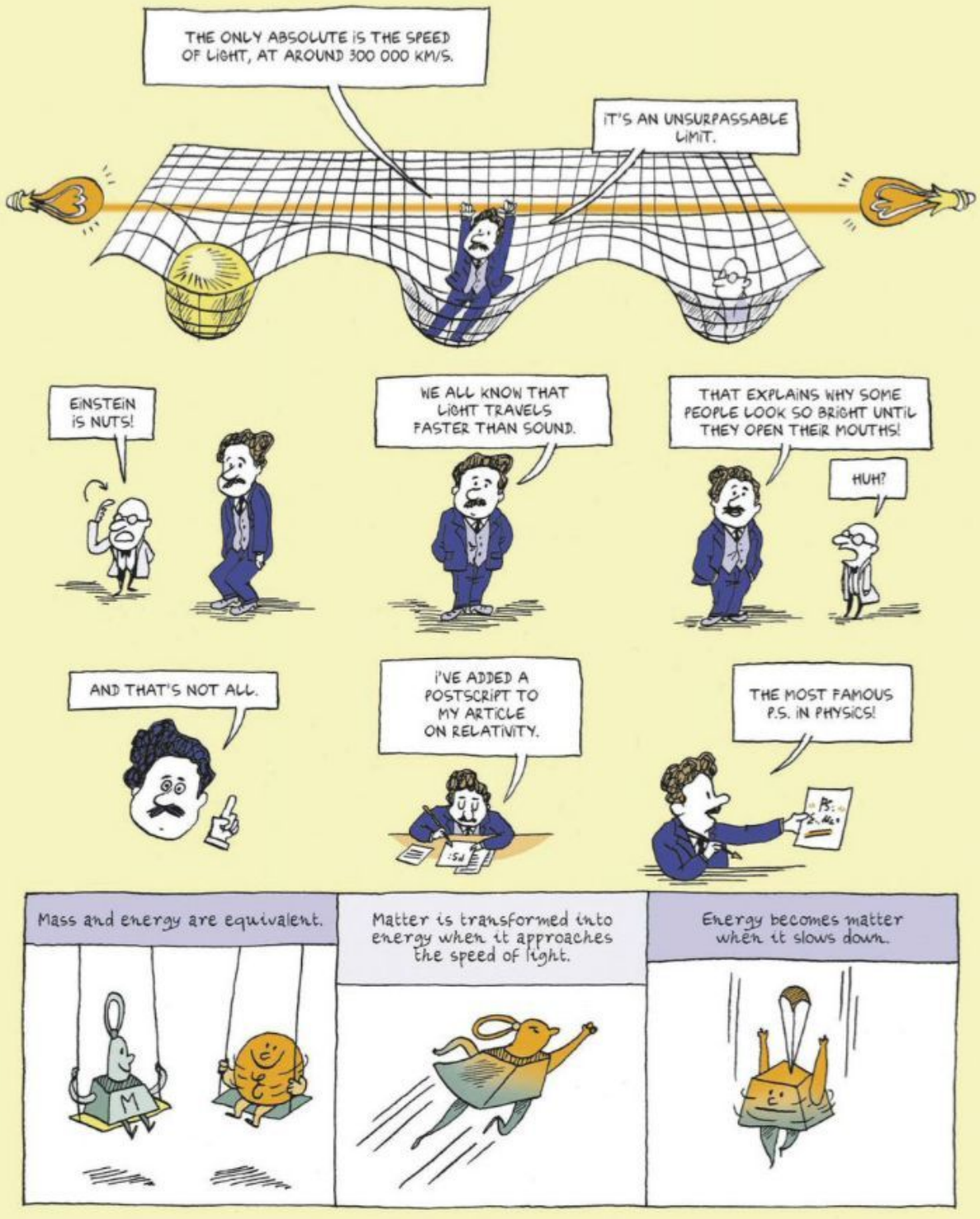
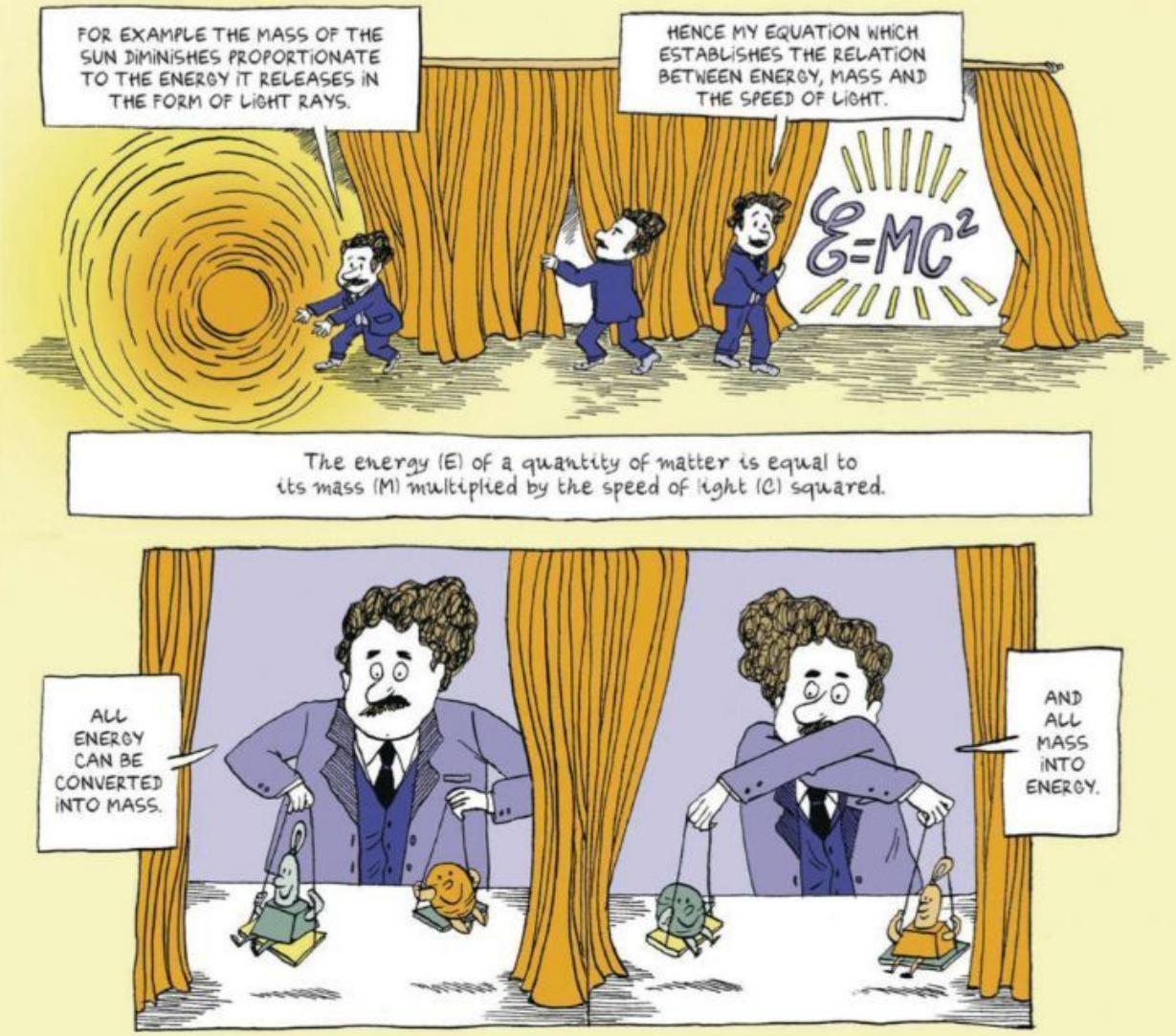


PHOTO: CORINNE MAIER/ANNE SIMON/NOBROW





01

REVEL IN RELATIVITY

2015 marked 100 years since Einstein published his General Theory of Relativity, and the past year has seen no end of tributes to the great physicist. But a new graphic novel from Nobrow Press has to be one of our favourites. Covering Einstein's life and ideas, this gorgeously illustrated biography is both playful and profound. In this extract, he explains his Special Theory of Relativity.

EINSTEIN: AN ILLUSTRATED BIOGRAPHY
BY CORINNE MAIER AND ANNE SIMON
IS OUT NOW (£13.99, NOBROW PRESS).

02

EMBRACE OUR MORTALITY

In his new book *Death On Earth*, JULES HOWARD explores death in the animal kingdom, asking what it can tell us about our own approach to death. He talks to JAMES LLOYD

Why did you decide to write a book about death?
I spent about three years looking at the evolution of sex [for my last book] and I realised that sex in the animal kingdom is heavily influenced by the chances of death – death is always there in the background. So I decided to investigate this. But what starts off as a journey into the evolution of life in the shadow of death turns into a broader exploration of mortality.

What was the most memorable experience you had while writing your book?
I visited a field where forensic scientists do pathological investigations on dead pigs to study how corpses decompose. It was just fascinating to see the myriad of life forms that have made death their home – clown beetles, rove beetles, parasitic wasps, maggots. What I thought would be a rancid, stench-filled hellhole actually turned out to be a fireworks show.

What was the most challenging part of your book to write?
It was the chapter about how and to what degree animals perceive death. We're famously told about elephants and chimpanzees mourning, but these are often anecdotes – it's very hard to assess what's going on in the animals' minds. I went to a donkey sanctuary and talked to the scientists about how the donkeys often display distress when they lose a stablemate. But is this true grieving and mourning, or are these just human labels?

Death is one of the last taboos in human society. Why do you think that we find it so difficult to talk about?
I think as a species we have a degree of narcissism and self-importance, and any reminder that we're a temporary blip in the history of life is difficult to deal with. And that's fair enough. Perhaps one of the things that makes us most human is our inability to properly get our heads around the fact that we're going to die.

Did writing your book change the way you think about death?
Well, I have a will now! This is going to sound like a cliché, but being immersed in death hasn't made me depressed – it's been really life-affirming, in a way I hadn't predicted.

DEATH ON EARTH: ADVENTURES IN EVOLUTION AND MORTALITY
BY JULES HOWARD
IS PUBLISHED ON 10 MARCH (£16.99, BLOOMSBURY SIGMA).

Donkeys are known to show distress when their friends die

PHOTO: GETTY



Will Mark's creations receive a chilly reception? Or will Marcus be thoroughly beaten?

WATCH CHEF VS SCIENCE: THE ULTIMATE KITCHEN CHALLENGE

ON BBC FOUR THIS MARCH – CHECK RADIOTIMES.COM FOR FULL DETAILS.

03

LEARN HOW TO COOK LIKE A SCIENTIST

Is cooking a science or is an art? Can anyone cook the perfect meal with the right equipment, or does it require a flash of culinary brilliance? This month, we're about to find out.

In the red corner: Prof Mark Miodownik – materials scientist at University College London and aspiring cook. In the blue corner: Marcus Wareing – *MasterChef* judge and the proud owner of two Michelin stars. Their task: to each cook a three-course meal of tomato soup, steak and mash, and chocolate fondant. One will use their decades of experience at the top of the culinary world. The other will use their scientific nous and an array of weird and wonderful equipment.

Will Mark Miodownik's starter be more soup or gloop? Will his steak be medium rare or a bit of a 'mare? And how on Earth will he attempt one of the trickiest desserts known to humankind? Tune in to BBC Four to find out.

PHOTO: BBC

PROF MIODOWNIK'S CULINARY TIPS
FIVE TRICKS TO TRY YOURSELF

1 USE A WATER BATH

Everyone should try cooking chicken or fish with a water bath. You can hit exactly the right temperature, and the results are utterly delicious.

2 PUT YOUR WINE IN A BLENDER

It may sound like sacrilege, but if you have a good red wine, stick it in a blender for 30 seconds. This will aerate it and bring the flavour to life.

3 EXPERIMENT WITH COLOURS

In the programme, I dye strawberry ice cream different colours to show how your sense of sight can fool your brain and affect your sense of taste. Explore the effect for yourself by drinking sparkling water out of different coloured glasses.

4 DRINK TEA WITH FATTY FOODS

If you're enjoying a juicy steak or a hamburger, try accompanying it with drink of black tea. This will clear the fat out of your mouth and act as a palate cleanser.

5 PLAY SOME MUSIC

"Your sense of hearing also affects your sense of taste. Try eating some dark chocolate while listening to bassy music and then something more tinny – you should find that different frequencies bring out different flavour notes in the chocolate."

04 SUPPORT OUR NEW DRONE HEROES



New television show *Airmageddon* pits teams of young aviators and their customised drones against each other in a battle for air supremacy

"The idea of doing a game show with flying machines has been in my head for a long time, but it was never effective with helicopters, balloons or planes," says Steve Carsey, the brains behind the show. "It just didn't have that special ingredient, and wasn't viable for a number of reasons. But with drones it is."

Each team is made up of two people – a young drone pilot plus an older wingman or wingwoman who'll provide a second pair of eyes (and moral support). They must work together to overcome challenges and other teams flying in the Airena, the indoor airspace that's been created for the competition in the vast airship hangars at Bedford's Cardington Studios.

"Each episode sees four teams enter the Airena for a three-round knockout competition," says Carsey. "The first round is the Airsault Course, which the teams take on one by one against the clock. The second round is a challenge that tests their flying ability, navigation skills, strategy and teamwork. And the final round is a head-to-head dogfight between the two surviving teams."

But the teams won't have the Airena skies all to themselves – they also have to contend with the fleet of resident drones, who'll introduce an element of jeopardy into the mix (see 'The resident drone fleet', right).

If the format – mechanised conflict and house robots – sounds familiar, it's





Will Best and Rachel Stringer present the futuristic new game show

WATCH *AIRMAGEDDON* ON CBBC EVERY SATURDAY AT 8.25AM

probably because Carsey is also a co-creator of *Robot Wars*, a rebooted version of which is returning to our screens soon. But whereas the contestants in *Robot Wars* constructed their own machines, the need to create a fair competition means the *Airmageddon* contestants' drones have all been built in-house. Which isn't to say there's not room for the teams to add some personal touches.

"The contestants' drones are coaxial octocopters [with two propellers mounted at each of the aircraft's four corners]," explains Carsey. "Technically, they're all the same, but the teams are allowed to enhance the fuselage and alter the look of their drone. They can have fun with the aesthetics but they have to be careful not to compromise their machine's flight dynamics."

Teams that change their drone's centre of gravity or add too much weight with flamboyant decorations will be at a disadvantage in the battle for the show's ultimate prize: the Airmageddon trophy. And Carsey hopes that the challenges will not only make for spectacular television but also help to remedy the public perception of drones and the people that fly them.

"Of course, you can expect to see crashes in *Airmageddon*, but you'll also see amazing piloting skills from our competitors, who are using the latest drone technology. It's a first for world television, let alone British television."

PHOTO: BBC X8

THE RESIDENT DRONE FLEET

Meet *Airmageddon*'s resident drones, who'll be making life difficult for the competitors

PIG

(PERSONALISED INTERACTIVE GYROCOPTER)

A practical joker who's constantly getting in the way of the action. When not causing mischief, PIG's primary function is to demonstrate how the challenges are played.



WASP

(WEAPONISED ASSAULT SHIP)

These drones function as rapid response units. They're fast, agile and dynamic – and have a sting in their tails.



DRAGON

(DIRECT RESPONSE AERIAL GYROCOPTER)

The DRAGON-class drone is intended to be a heavier duty WASP-style attack drone but with greater firepower – hence the front-mounted flamethrower.



GUARD

(GIANT UNMANNED AERIAL RECONNAISSANCE DRONE)

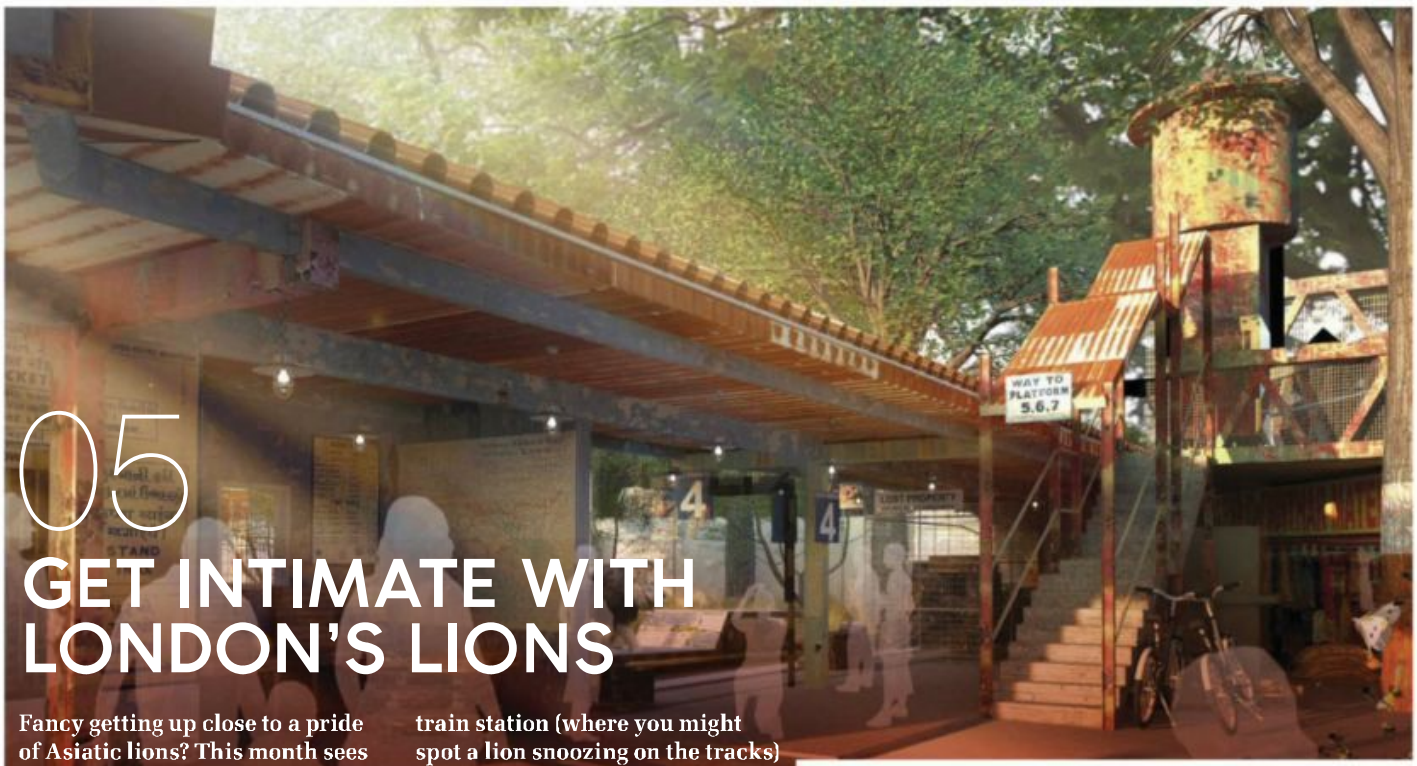
These drones serve as defence and observation units. They're the largest drones in the Airena and are controlled by AI algorithms.





AIR MARSHALLS

These are the show's 'airjudicators' – the referees, in other words.



05 GET INTIMATE WITH LONDON'S LIONS

Fancy getting up close to a pride of Asiatic lions? This month sees the opening of Land of the Lions – a new experience at London Zoo that lets visitors get within metres of these charismatic creatures.

There are only around 500 Asiatic lions left in the wild, and they're all found in the Gir Forest National Park in western India. Inspired by their natural habitat, this new attraction features a crumbling temple, a sun-scorched train station (where you might spot a lion snoozing on the tracks) and an Indian high street. A 'windowless view' means that visitors are separated from the big cats only by fine wires, while an overhead walkway plays host to a troop of monkeys.

And for those who don't want to go home, the new Gir Lion Lodge will let visitors stay in luxury accommodation within roaring distance of the lions. Claw-some!

LAND OF THE LIONS

OPENS AT ZSL LONDON ZOO ON 25 MARCH.

DON'T MISS

TOTAL SOLAR ECLIPSE

Indonesian skywatchers will be enjoying a total eclipse of the Sun on 9 March. Parts of Southeast Asia and Australia will also witness a partial eclipse. Go to skyatnightmagazine.com for more information.



06 GRAB A FREE PAIR OF TICKETS FOR THE *GADGET SHOW LIVE*

Technophiles rejoice! We've teamed up with Gadget Show Live to give away tickets for the UK's largest consumer technology exhibition at the NEC Birmingham, 31 March – 3 April 2016. We have 5,000 pairs (count 'em!) of complimentary e-tickets up for grabs, valid for either the Thursday or Friday.

At the show, you'll be able to get your hands on the latest gizmos, from drones and games to wearables and fitness tech, as well as watch a new live show in the Super Theatre. What's more, we'll be there too, so you can meet your favourite magazine team in the flesh.

All you need to do to claim your two tickets is head to **gadgetshowlive.net/bbcfocus** and complete the online form by 21 March 2016.

PHOTOS: ZSL

TERMS AND CONDITIONS:

· Only two tickets per reader email will be issued. · There are 5,000 pairs of tickets available: 2,500 each day for the Thursday and Friday. These will be issued on a first come, first served basis. · Tickets are only valid for the selected day. No exchanges can be made for alternative days. · Only entry tickets will be issued. If you wish to visit the Super Theatre you will need to purchase these tickets separately. · Offer closes 21 March 2016, or after the 5,000 pairs of complimentary e-tickets have been issued (whichever is soonest). · Our normal ticket terms and conditions apply, please head here for more information: **gadgetshowlive.net/terms--conditions**

PROF **AOIFE MCLYSAGHT** SHARES HER FAVOURITE SPOTS IN **DUBLIN**



There's so much to love about Dublin. It's a European capital city, on the sea, with mountains in the background and one of the largest urban parks in Europe – Phoenix Park. I love strolling there in the evenings to watch the fallow deer running free. One of the best things about Dublin is that it's so 'walkable' – you can easily go from cultural institutions to restaurants to gig venues.

At the **SCIENCE GALLERY** ❶, exhibits change every three months, so there's always something new to explore. Meanwhile, the National Museum is filled with beautiful historical artefacts. My favourite is an exquisite model of a boat, finely crafted from gold. But the **NATURAL HISTORY MUSEUM** ❷ is a special treat. Known as the 'Dead Zoo' by locals, it's a treasure trove of creatures of all shapes and sizes. It's peaceful and quiet – I love to think about the people who made these collections. It opened one year before Darwin published *On The Origin Of Species*, and has some pieces that were actually collected by him.

Being on the River Liffey, Dublin has some stunning bridges. The architect Santiago Calatrava designed the **SAMUEL BECKETT BRIDGE** ❸, which looks like a harp – one of the symbols of Ireland. **BROOME BRIDGE** ❹ passes over the Royal Canal, and is reputedly where the Irish scientist Sir William Rowan Hamilton etched his mathematical formula into the stone. The story goes that he had a moment of insight and didn't want to risk forgetting it, so wrote it down with the only materials available. This was the fundamental formula for what are now called 'quaternions', which are the basis for 3D graphics in computer games.

When it comes to food, one of my favourite spots in Dublin is a great Italian called **DUNNE & CRESCENZI** ❺ that's approved by my Italian friends. Their ravioli with mushrooms and truffles is worth a special visit. The Cake Café is a wonderful spot for brunch. Tucked behind a paper shop, when you enter you feel like you've found a hidden gem. And **WHELAN'S** ❻ on Wexford Street has loads of great gigs. It's a rite of passage for all the best up-and-coming musicians. I once saw the Hollywood actor Tim Robbins play a set there with his band. F

ILLUSTRATION: TONWEN JONES

❶ SCIENCE GALLERY
Exhibitions regularly change at this great venue.
Pearse Street
dublin.sciencegallery.com

❷ NATURAL HISTORY MUSEUM
This vast natural history collection also includes animals native to Ireland.
Merrion Street
museum.ie/Natural-History

❸ SAMUEL BECKETT BRIDGE
This modern cable-stayed bridge connects Sir John Rogerson's Quay with North Wall Quay.

❹ BROOME BRIDGE
The stone bridge across the Royal Canal where Sir William Rowan Hamilton etched his famous formula back in 1843.

❺ DUNNE & CRESCENZI
Traditional trattoria serving a typical Italian menu of simple dishes.
14-16 South Frederick Street
dunneandcrescenzi.com

❻ WHELAN'S
Great gig venue, featuring all genres of music.
25 Wexford Street
whelanslive.com

Aoife McLysaght is a genetics professor at Trinity College Dublin.



NEXT MONTH



APRIL ISSUE ON SALE 31 MARCH

TECHNOLOGY

Welcome to the drone age

Drones aren't just for big kids. Discover how these unmanned vehicles are flying us into a new era of exploration, allowing scientists to glimpse never-before-seen worlds.

HEALTH

ALLERGIES: THE TRUTH

Supermarket shelves are increasingly being filled with gluten-free, dairy-free products. But is the growing 'free from' movement also free from facts?



ENVIRONMENT

POISONED PLANET

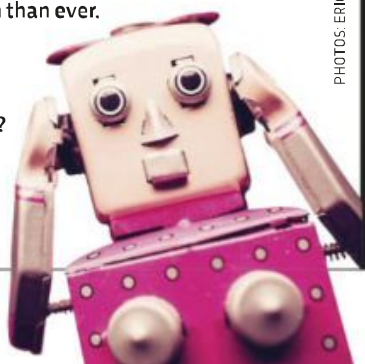
Thirty years after the Chernobyl disaster, we look at how humans are adapting to life in some of the most hazardous and inhospitable places on Earth.



PSYCHOLOGY

PORN ON THE BRAIN

As a society, we're watching more porn than ever. But what effect is it having on our minds?



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CONTRIBUTORS
Acute Graphics, Neil Ashton, Robert Banino, Peter Bentley, Heather Bradshaw, Daniel Bright, Jamie Carter, Matt Clough, Jamie Coe, Helen Czerski, Luke Edwards, Valentina D'Efilippo, Sam Falconer, Louisa Field, Adam Gale, Duncan Geere, Alastair Gunn, Robin Ince, Christian Jarrett, Tonwen Jones, Tim McDonagh, Magic Torch, Peter Moore, Lisa Moses, James Olstein, Jhani Osman, Helen Pilcher, Dean Purnell, Andy Ridgway, Matt Swaine, Luis Villazon, Ian Whittaker

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Head of UK publishing Chris Kerwin
Publisher Mandy Thwaites
Publishing coordinator Eva Abramik
Contact UK.Publishing@bbc.com
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EDITORIAL COMPLAINTS
editorialcomplaints@immediate.co.uk

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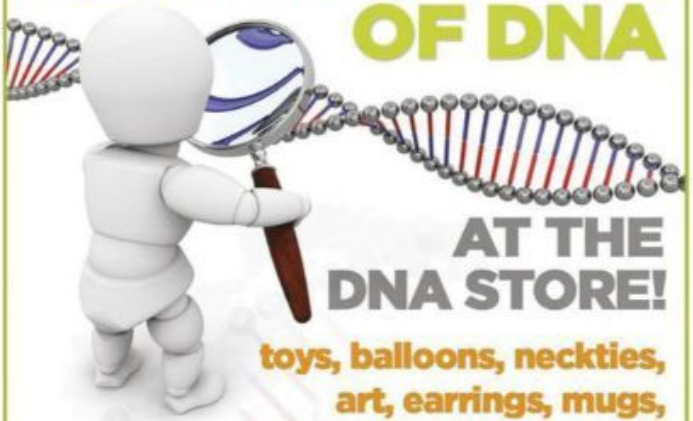
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A very interesting simple and fun toy. When the lower portion of the glass sculpture is held, the liquid rushes into the upper section, and appears to boil furiously. Then hold the top section and liquid returns to the bottom.



Ferrofluid is a runny fluid that is magnetic. Hold a magnet to it and watch how it reacts. Some of the shapes you are can create are mesmerizing.

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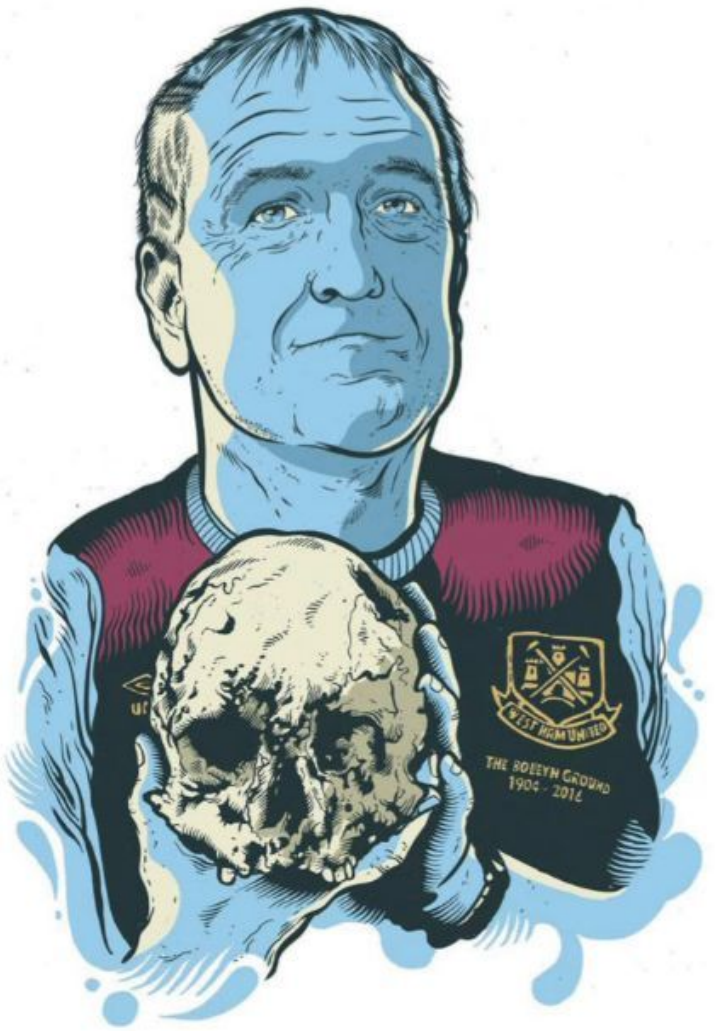
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"Were encounters friendly, or were modern humans stealing Neanderthal females?"

Prof Chris Stringer is research leader in human origins at London's Natural History Museum



When I started working at the Natural History Museum in 1973 it was incredibly formal. Men wore jackets and ties, and women weren't allowed to wear trousers. Back then the museum was part of the civil service, so I had to sign the Official Secrets Act!

When I was seven, I made a Mesolithic village out of papier mâché. When I was nine or 10 I did a school project on Neanderthals. They have fascinated me ever since.

No one ever told me that you could have a career in anthropology. At secondary school I was on track to go into medicine. But then by fluke a friend brought me the University College London prospectus and it fell open at the anthropology page. My teachers were sceptical but my parents were open-minded, so I switched to do that.

One of the most exciting moments for me was when researchers first recovered DNA from a Neanderthal. Nineteen years later, we have the whole genome. It's an incredible achievement. Human evolution never gets tiring because new discoveries are being made all the time.

I've come to expect the unexpected. Studies of ancient DNA reveal that modern humans and Neanderthals interbred in the past, but I'd really like to know how that happened. Were these friendly encounters or were modern humans stealing Neanderthal females?

I'm a big West Ham fan. When I was a kid, my dad and my uncle used to take me to watch them play. The team is moving to the Olympic Stadium later this year but Upton Park will always be one of my favourite places.

I'm really excited by the new human evolution gallery at the Natural History Museum. We have a replica skeleton of the hobbit, *Homo floresiensis*. It's incredible; an adult was about the same size as a modern three-year-old child. We've also got a wall of skulls that charts our seven-million-year-old backstory. It includes *Homo naledi*, which is the newest species of hominin to be discovered.

I'm proud of what I've achieved at the Natural History Museum but I'm also proud of my three kids. One of them even works for West Ham.

If I wasn't a scientist, I'd be working for West Ham. Or I'd be writing music. People said the songs I wrote 40 years ago sounded a bit like Leonard Cohen's!

I'm a keen amateur astronomer but I live in London where there's a lot of light pollution. So I've loaned my telescope to a friend who lives in Shropshire.

It's great to still be here. I was diagnosed with prostate cancer a few years ago, but it got caught early. Hopefully that's that!

Prof Chris Stringer is a UK expert on human origins. His most recent book is *Britain: One Million Years Of The Human Story*.

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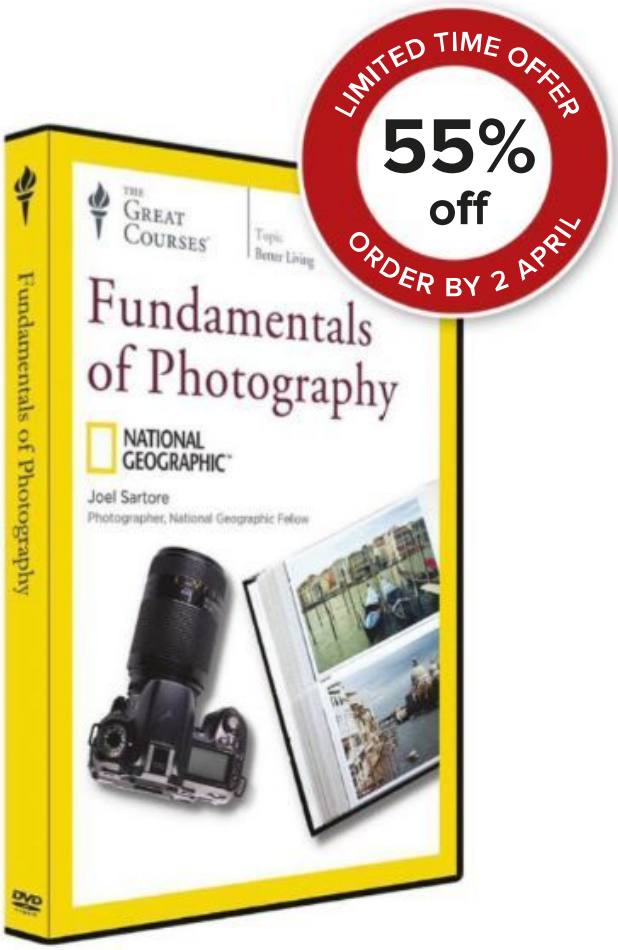
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